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Design of Semi-physics Simulation Training System for Offshore Drilling Electrical Engineers ⋆

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Abstract: As the automatic drilling control system is more widely adopted in the field of offshore oil drilling, the integration of the control system has brought the electrical engineers more challenges to the system troubleshooting. There is an urgent need to propose a low-cost training solution for electrical engineers. Therefore, a semi-physics simulation training system of offshore drilling specifically designed for electrical engineers is addressed in this paper. To maintain high simulation fidelity, driller chairs and PLC controllers are copied and realized from field. Mathematical models are built to simulate both normal and fault state of the drilling control system. Different faults are realized by changing the setting parameters of model or switching between faulty models. Finally, with the help of virtual reality technology, the 3-D environment of drilling operation is realized to improve the vision performance. Moreover, an instructor station subsystem is designed to evaluate trainer's performance. Through this simulation training system, the electrical engineers can not only master drilling control system, but also improve the troubleshooting skill.

Keywords: Semi-physics, simulation training system, offshore, drilling rig, electrical engineers.

1. INTRODUCTION

With the increasing demand for oil and the difficulty of offshore drilling, the petroleum industry has greatly increased the requirement for the efficiency, precision and complexity of oil drilling equipment. Therefore, the automatic drilling control system has been widely used in offshore oil drilling platform, and it has become the dominant configuration of the global offshore oil drilling platform. For this highly integrated drilling control system, the troubleshooting or fault isolation is a challenge for electrical engineers on the platform. To improve electrical engineers' troubleshooting capability, it is urgently necessary to specifically design a drilling simulation training system, in which faults can be generated and preferred troubleshooting workflow is detailed.

Most of the drilling simulation training systems are only effective to drillers for the drilling operation training. To the best of our knowledge, there is no any simulation system particular for training of the electrical troubleshooting issue.

There are several drilling simulation system providers in the market, such as Aberdeen, Hidrill, and so on. For Aberdeen Drilling Management simulator, the operating compartment is a full-size replica of the driller's control cabin on the offshore drilling rig and there are display screens around to show 3D graphics of equipment such as rigs and derricks, Hodgson and Hassard (2006). But this system cannot train the electrical engineers' ability of troubleshooting.

For the Hidrill simulator, it is the drill pipe processing and advanced drilling simulator, complete 3D display of the drilling environment. More details about it, refer to Odegard et al. (2013). All the important rig equipment are controlled through the driller's operating chair, hence simulator consists of control system, logic and alarm system. Similarly, this simulator can only be used to train the driller's operation ability.

And also, there are many concerns of drilling simulation in academic community. Based on Payzone simulator, see Mahmoud et al. (2012), Kelessidis fully simulates the drilling process in Kelessidis et al. (2015). Mirhaj design a 3D virtual drilling simulator to train tripping operation of the operator, see Mirhaj et al. (2013). Aragall and Blikra based on advanced dynamic set up a simulation training system, see Aragall et al. (2017) and Blikra et al (2014). So, this paper presents a method to design a drilling simulation training system which can not only train the ability of operation, but also train the ability of troubleshooting.

Though there are so many and valuable progress on drilling simulation training, there is no any solution to carry out the

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training of troubleshooting. For this sake, a design solution of a semi-physics drilling simulation training system is presented in this paper. Different with other simulation training systems, which can only train the ability of operation, the proposed semi-physics drilling simulation training system can also be used to train the operator's troubleshooting ability. To improve the training performance, both software and hardware faults common in the field should be considered and hence it is necessary that some hardware instruments are remained in the training system.

The rest is organized as follows. In section 2, the drilling simulation training system structure is defined. In section 3, based on this structure, several subsystems are detailed. Finally, in section 4, concluding remarks are given.

2. OVERALL STRUCTURE DESIGN OF DRILLING SIMULATION TRAINING SYSTEM

As shown in Fig. 1, the electronic driller system can be divided into three parts: the operator station , PLC control system, field As shown in Fig. 1, the electronic driller system can be divided into three parts: the operator station , PLC control system, field equipment and instruments. The operating station is responsible for issuing control commands and displaying field devices status information; the PLC control system is responsible for the communication between the operationg station and the field devices; the field devices and instruments are responsible for executing the control commands of the operating stations and uploading the status information of each device, such as measuring data, device status, and so on.

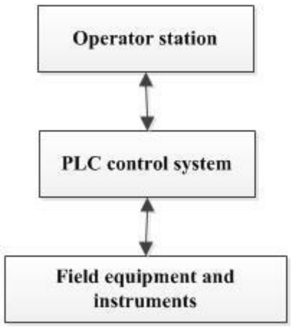

Fig. 1. Schematic diagram of automatic control system for drilling.

In order to setup a drilling simulation training system specific for electrical engineers, a semi-physics solution is presented. According to the structure of the automatic drilling control system, the overall structure of the simulation training system is designed as shown in Fig. 2.

As shown in the Fig. 2, in the semi-physical simulation training system, in order to improve the training effect and meanwhile reduce the complexity of the system, hardware items in the operation station and PLC control system of the automatic drilling control system will be retained, while the field equipment and instruments will be replaced by their mathematical models, the corresponding 3D display system and fault setting system. It can be seen that the simulation training system consists of four subsystems, i.e. control subsystem, model computer subsystem, coach station subsystem, and virtual reality subsystem.

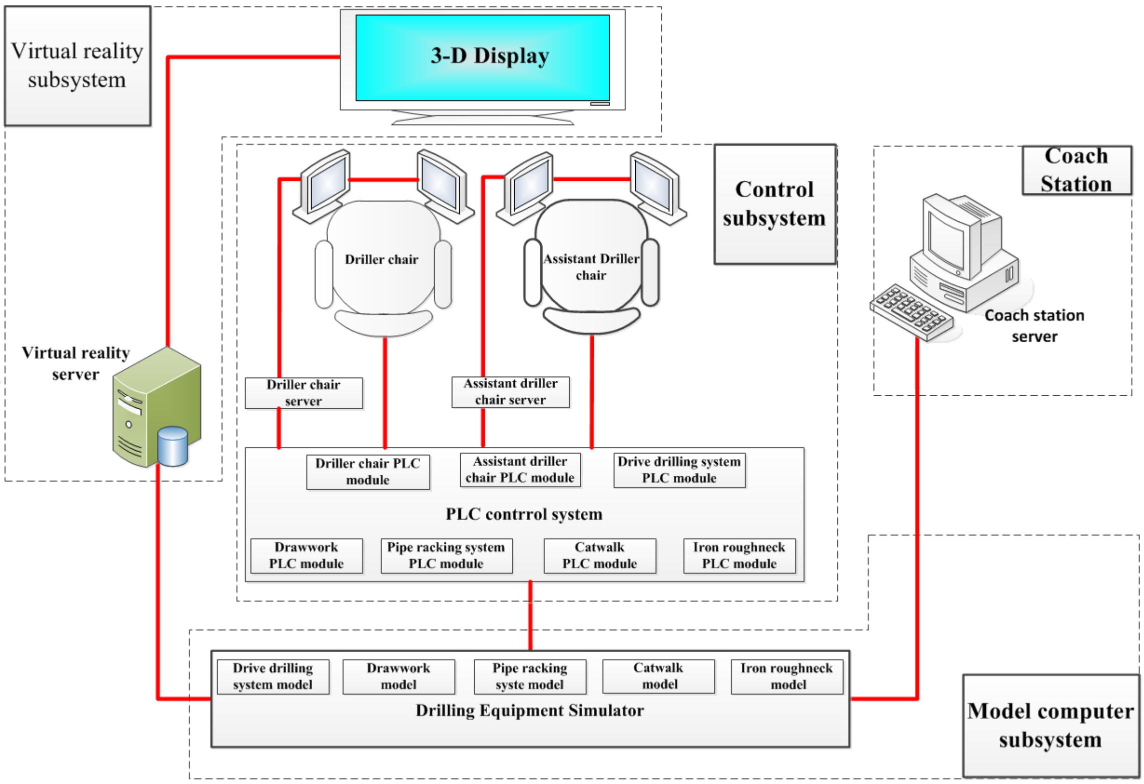

Fig. 2. Schematic diagram of simulation training system.

The control subsystem, including the operator station and the PLC control system, is responsible for issuing control commands and receiving information from the model computer subsystem. To guarantee the training effect, the physical instruments are adopted for this part.

To simulate the field equipment and instruments, a model computer subsystem is proposed here, in which all the equipment and instruments are described in mathematical models. model computer subsystem is replaced with all real-world equipment, which communicates with the control subsystem, accepts the control command, realizes the simulation of the working condition using the established mathematical model of the field equipment in the model computer, and transmits the resulted information of the equipment (i.e. motion speed, equipment position and so on) back to the control subsystem. With the help of mathematical models, both the normal and faulty operation cases can be realized.

The coach station subsystem performs operators' evaluation and fault generation task. It communicates with the model computer subsystem, and provides access to change the parameters of the model of each device and set the fault.

The virtual reality subsystem builds the 3D model of the drilling rig through 3D modeling software and visual simulation software. It also receives the data from the model computer subsystem and then transforms them into executable commands to drive the three-dimensional model move. The virtual reality subsystem provides an intuitive sight of the working condition of the drilling control system, which is designed for training effect.

The integration and interaction of these subsystems realizes both the operation training of filed equipment and troubleshooting training. The operating training program makes drilling electrical engineers familiar with, (i) ordinary process operation, such as drill pipe loading, disassembling process, drilling process and so on, and (ii) instruments, such as catwalk, drive drilling system, draw work, pipe racking system, iron roughneck. The troubleshooting program trains the electrical engineer's fault shooting ability to locate the electrical faults in drilling control system during drill pipe loading and dismantling process, and drilling process.

3. SUBSYSTEM DESIGN OF SIMULATION TRAINING SYSTEM

Based on the above introduction to the overall structure of simulation training system and the function of each subsystem, this chapter mainly designs each subsystem to make the simulation training system achieve the goal of training the electrical engineer of offshore drilling platform.

3.1 Control subsystem design

In order to realize the functions of the control subsystem described above and make the system meet the training operator requirements, the control subsystem should include the driller's chair, server, and the PLC control module, as shown in Fig. 3. Moreover, physical devices are adopted for this part.

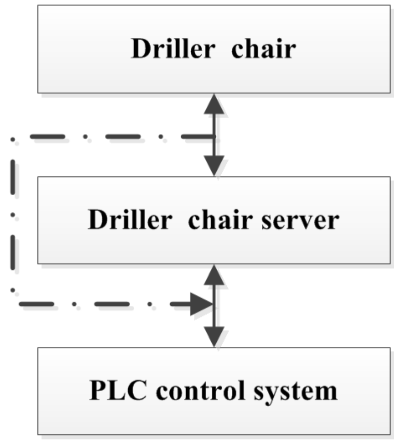

Fig. 3. Schematic diagram of control system.

It can be seen from the Fig. 3 that, in order to meet the requirements of the training operator for the operation and troubleshooting of the equipment, an physical operator's chair is set in the control subsystem, by which the operators can have the access to understand the status information of each equipment and set the system parameters by operating the joystick, keyboard and mouse, observing the display on the driller's chair.

Moreover, the real PLC module in the control subsystem is set to enhance the operator's actual disassembly and assembly capability of the PLC module. It is worth mentioning that, in order to better simulate the drilling control system, the driller's chair and each field device should be equipped with separate PLC control modules. Each device's PLC control module should be equipped with CPU, AI/AO, and DI/DO modules. To ensure the stability of the simulation training system, as shown in Fig. 4, the individual PLC control modules are connected to constitute a ring network to ensure data transmission.

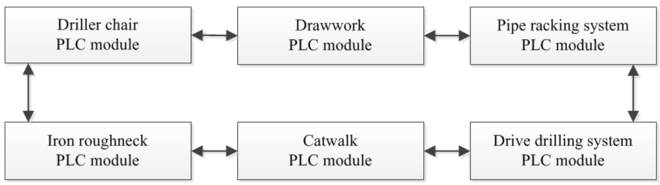

Fig. 4. PLC system network connection diagram.

The drilling server stores all measuring data, control command data and device status data. It also provides communication between the operating station and the PLC control system.

3.2 model computer subsystem design

In order to realize the function of the model computer subsystem described above, the model computer subsystem should have potential for electrical fault setting and fault simulation. The model computer subsystem is realized as a simulator, which can load the mathematical modelling software, and perform the corresponding operation according to the control subsystem and the coach station. The structure is shown in Fig. 5.

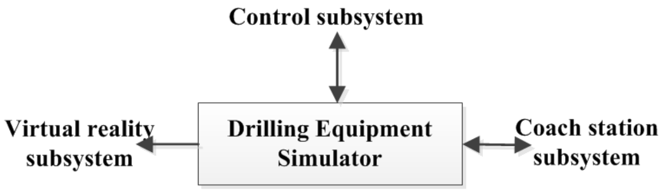

Fig. 5. Schematic diagram of model computer subsystem.

What should be highlighted is the model here covers both normal and faulty conditions. In other words, both normal operation model and fault description model are included in this model computer subsystem.

For the drilling model under normal conditions, mathematical models for every drilling equipment are built based on their specific mechanism and data collected from the field platform. That is to say, for some equipment with clear known mechanism, the mathematical model is obtained through its mechanism analysis; for some equipment without clear mechanism, then the data driven method is used to drive the mathematical model. For example, for draw work, when top drive load is 0 Kg, input voltage of draw work motor is 600 V, frequency of draw work motor is 60 Hz, the top drive rise rate and time curve are given by the established mathematical model, as shown in Fig. 6.

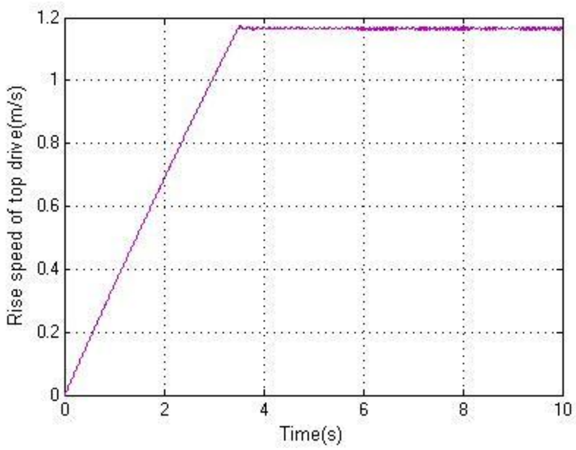

Fig.6. Rise speed curve of top drive under normal conditions

It is rather difficult to describe the faults because they are generated from multiple sources with distinct characteristics, including both hardware and software faults. To overcome this difficulty, we divide all the faults into two categories: parameter related slowly changing fault and state-switch fast changing fault. All these two class faults are triggered at the coach station, but realized in different ways.

For the fault triggering conditions, we should first understand how does the drilling automatic control system determine a fault? As we all known, any failure will inevitably lead to a related variable's value beyond its normal range, and drilling automatic control system can identify it by comparing the reference value of the variable with the value of the variable. That is to say, if the value of the variable is beyond the normal range, some failures of the system occur. Therefore, according to this principle, an interface in the coach station is designed to set faults and fault triggering variable generated from the setting action is then transferred to the mathematical model in the model computer subsystem to further simulate this fault. Hence, the coach station can change the value of the variable at a moment through the interface and set a logic judgment module in the model computer to judge whether the variable is beyond the normal range, if it is beyond the alarm, the failure occurred, and logic judgment module according to the different variables output '0' or '1'.

For the indication of fault occurrence, it is well known that in the drilling automatic control platform. When a fault occurs, the operation station will post alarm message. According to the type of the fault, operator can then decide whether or not a true fault occurs. Through the output value of logic judgment module, model computer module can activate the alarm module and non-alarm module in the mathematical model, and make the model in the model computer enter the fault state. By this way, fault setting function is realized. Moreover, life-like alarm message function is realized.

Similarly, once the operator identifies the source of the failure, through the communication between operator's chair and the coach station interface, human-interfering variable will then work on the mathematical model in the model computer and the value of the variable will be changed after simulation. If source identification and adjustment (i.e. human interfering variable) are correct, the alarm message will disappear and system returns back normal state. The structure of mathematical model in model computer subsystem is shown in Fig. 7. For draw work, while top drive load is 0 Kg, input voltage of draw work motor is 600 V, frequency of draw work motor is 60 Hz, the motor winding temperature exceeds its reference set from the coach station at 6 s, the motor will slow down and speed down to 0. By identifying this point, the operator targets this fault at 12 s. The top-driver rise speed curve is shown in Fig. 8.

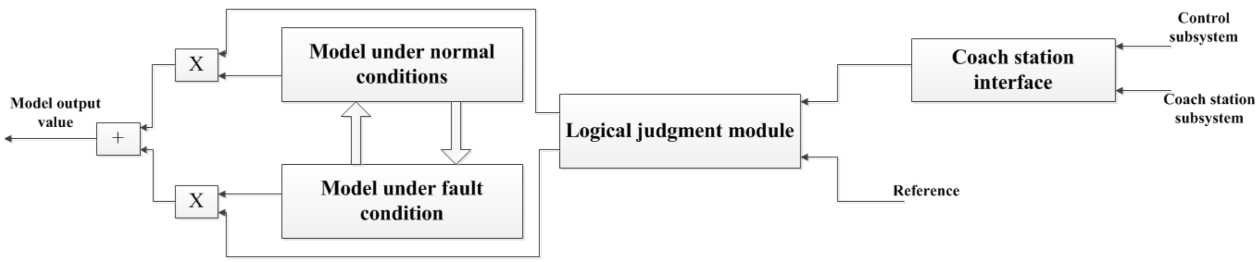

Fig.7. model computer subsystem model structure.

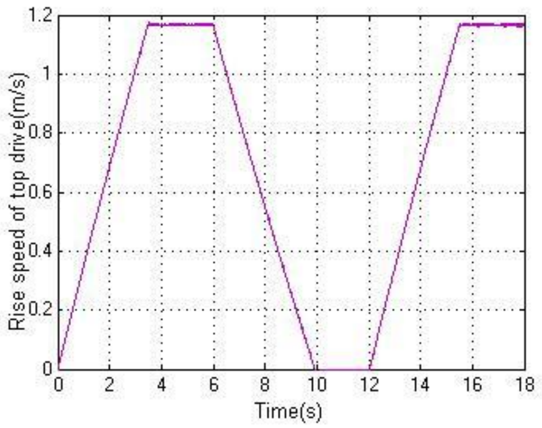

Fig.8. Rise speed curve of top drive under fault conditions

It should be noted that in the model computer subsystem, the communication between the normal state model and the fault state model should be ensured, so that the model can switch between the two states.

3.3 Coach station subsystem design

From the aforementioned analysis, it is shown that the coach station subsystem in simulation training system mainly performs the fault setting and operator's performance evaluation. To realize these functions, a server with the corresponding software should be equipped to communicate with the model computer subsystem for fault setting data transfer and evaluate the operator's operating performance automatically. The structure for coach station subsystem is shown as Fig. 9.

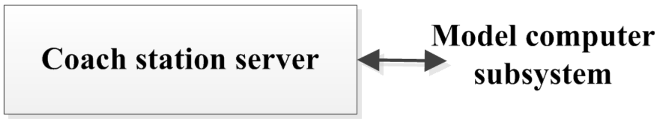

Fig.9. Schematic diagram of model computer subsystem.

There are two ways to realize the faults in the coach station subsystem. One is to change parameter's value for parameter-related slowly changing faults, and the other is to make a switch between normal condition and faulty condition for state-switch fast changing faults. Not only parameters but also state switches variables are then transferred to model computer subsystem to carry out particular model calculation.

To make a comprehensive performance evaluation result, two individual scoring systems, i.e. computer scoring and the coach scoring system, are proposed here.

Computer scoring system is scored from the quality of typical case repair. According to the operation process of each typical case, the entire typical case is divided into multiple operation processes. And each operation process is further decomposed into multiple operation steps. The operation steps are the "atomic" scoring units of the computer scoring system. The score of the operation is the sum of the scores of each operation step, and the score of the automatic scoring is the sum of the scores of each operation. In order to truly reflect the real level of the electrical engineer, the final score of the computer scoring system is obtained by weighted average. The weight coefficient varies according to the case.

Correspondingly, coach scoring system should be scored based on the operator proficiency, emergency treatment and so on. Unlike computer scores, coach scoring system grants more emphasis on aspects that are difficult to quantify during the repair process, such as when operators are in the event of an accident, the impact of his psychological endurance on the process of troubleshooting. Similar to the computer scoring system, the coach scoring system will result in a weighted score according to the degree of each operation importance in the typical case.

Finally, a comprehensive score of scoring system by weighting between these two scores.

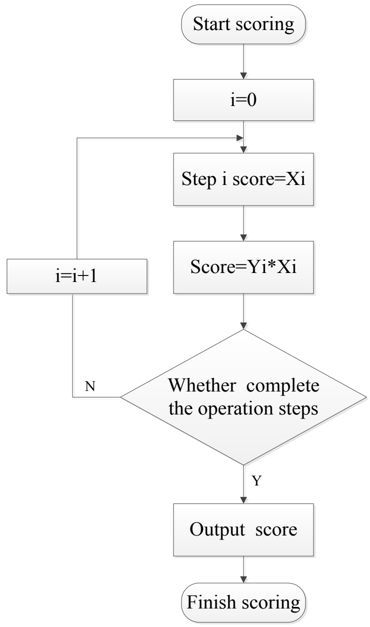

Fig.10. Structure diagram of scoring algorithm.

Scoring algorithm structure is shown in Fig. 10, where Y_i is the weight of step i, X_i is the score of step i, and $Score$ is the total score from step0 to step i.

3.4 Virtual reality subsystem design

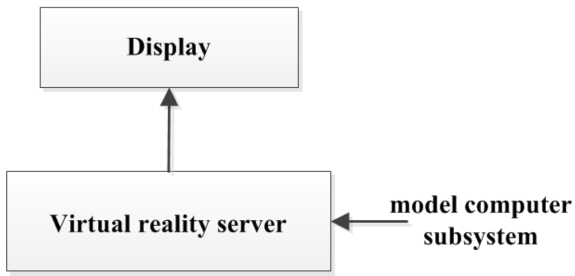

Fig. 11. Schematic diagram of model computer subsystem

To implement the functionality of the virtual reality subsystem described above, that is, the system is enabled to simulate the drilling environment, the subsystem should contain virtual reality server and display. The structure is shown in Fig. 11.

The corresponding software is loaded in the virtual reality server to realize the three-dimensional model of the field equipment and the visual simulation of the drilling environment. By receiving the information from the model computer subsystem, the three-dimensional model of the equipment is generated to simulate the real drilling operation. Then, through display devices such as VR helmets, splicing screens and so on, the simulated drilling environment is displayed. Making the operator listen, see and feel in line with the real drilling platform can definitely improve the training effect.

4. CONCLUSIONS

To well train electrical engineer on offshore platform and improve their troubleshooting ability, a semi-physics drilling simulation training system specific for electrical engineers is designed in this paper. Four major subsystems are detailed. To improve the electrical engineer's hardware troubleshooting ability, control subsystem remains same as field control system. To generate and simulate different faults, normal model based parameters changing method and state-switch based faulty model method are given. To well evaluate the operator's performance, a comprehensive computer and coach scoring mechanism is detailed in the coach station subsystem. The virtual reality subsystem simulates the drilling environment to provide an intuitive sight for operators. From these four subsystem explanation, it is clear that the proposed system can not only train the drilling operator, but also train the electrical engineers. The proposed solution compensate the most drawback of the dominant offshore drilling simulation training systems.

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