Research on the Real-Time Mechatronic System Simulation Based on Virtual Reality

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Abstract. Large-scale equipment has the characteristics of complicated structure with the hazardous working conditions such as high temperature, high pressure, high voltage and other extreme and dangerous environment, which is difficult for operators to master the use of this kind of equipment in the field with short time. The virtual reality technology provides the possibility for operators to receive remote virtual training in a safe place, and has been the hotspots recently. In this paper, a mechatronic system simulation method is proposed for operators to master the use of large-scale mechatronic equipment with the help of virtual reality technology. The real-time simulation of virtual mechatronic system is achieved by the task scheduling, fault injection, mechatronic system and load simulation, where the Levels of Detail (LOD) technology, parallel simulation technology, distributed simulation technology and batch processing technology are used to further optimize the system scheduling time. With the combination of multi-channel video images and dynamic video adjustment, a suitable way to construct the display screen can be selected, and the operator can complete the training with a better perspective, which achieves the purpose of virtual training. Finally, the example of a mechatronic system simulation interface is implemented to verify the effectiveness of the simulation method.

Keywords. Virtual reality; real-time; mechatronic system; unity 3D.

1. Introduction
With the development of automation and manufacturing [1-5], many large-scale mechatronic systems come into being and play an important role in many fields such as the marine sampling, production in the assembly line, etc. However, the use of these large-scale mechatronic systems has the following challenges:

(1) The equipment structure is complicated, which includes the mechanical, hydraulic, and electronic subsystems with various types of actuators and sensors and software. Without strict and in-depth study and training, operators cannot fully grasp the equipment use skills [6, 7].

(2) The operation flow is complicated. During the operation, multiple operators need to cooperate to complete the operation, and also need to communicate and cooperate with the surveillance and command personnel. In addition, it also involves mechanical, hydraulic, power distribution, cooling, remote operation, local operation, manual intervention, monitoring patrol and other operational steps. If it encounters abnormal working conditions or equipment failure, it will increase the difficulty of processing [8].

(3) High requirements for operators. Operators are required to fully grasp the system principle and structure, and be able to judge and take corrective measures in the event of equipment abnormality or emergency conditions [9, 10].
(4) The limitations of actual equipment training. The actual equipment training requires the operators to move to an operable area, which is limited by the working conditions. Due to hydraulic and electrical reasons, it is difficult to implement the training outside normal functions, which greatly reduces the training time. In addition, the training content cannot completely cover all kinds of faults and emergency working conditions, and the actual equipment training risks are relatively large. Incorrect work operations may cause great equipment loss and personnel safety issues [11-13].

In view of the above-mentioned challenges, it is difficult for operators to master the use of these equipment in a short time [14, 15]. Recently, with the development of computer science and technology, virtual reality technology comes into being, which provides the possibility for operators to receive remote virtual training in a safe place [16-18]. Especially for large-scale mechatronic systems, since the training process is complex and difficult, the development of virtual training platforms based on virtual reality technology will definitely become an important content in this field, and has been widely studied by scholars at home and abroad [19]. Google’s Waymo automated driving team developed a car-craft software as an acceleration tool for purpose of developing autonomous driving. The team rebuilt the real world by building physical channels on test vehicles to create digital real-world driving [20]. Microsoft developed an Air-Sim system for autopilot vehicle testing based on the virtual reality, which can be used to train the intelligence systems [21]. The collaborative virtual reality neurorobotics Lab designed an immersive interface to the NRP with an innovative soft and hardware infrastructure for collaborative virtual reality [22].

However, though there are currently many virtual-reality-based training platforms, most of them lack real-time performance and the physical scenes are unreal. Therefore, a mechatronic system simulation method is proposed in this paper for operators to master the use of large-scale mechatronic equipment with the help of virtual reality technology. The real-time simulation of virtual mechatronic system is achieved by the task scheduling, fault injection, mechatronic system and load simulation, where the Levels of Detail (LOD) technology, parallel simulation technology, distributed simulation technology and batch processing technology are used to further optimize the system scheduling time. With the combination of multi-channel video images and dynamic video adjustment, a suitable way to construct the display screen can be selected, and the operator can complete the training with a better perspective, which achieves the purpose of virtual training. Finally, the example of a mechatronic system simulation interface is implemented to verify the effectiveness of the simulation method.

2. Mechatronic System Simulation Architecture
The mechatronic system simulation architecture is shown in figure 1, which is mainly composed of five parts: task scheduling module, fault injection module, mechanical simulation module, and load simulation module. The detailed instructions of sub-modules are in the following.

2.1. Task Scheduling Module
The scheduling module of mechatronic system simulation architecture needs to complete the functions of self-running, extension model selection, working mode selection, and typical operating mode selection. Its main technical indicators are that the module has the ability to control of mechatronic system simulation unit, automatically adjust the parameters in multiple operating modes, allocation and scheduling of parallel computing tasks. The data flow of scheduling module can be seen in figure 2.

Namely, the control of mechatronic system simulation unit is achieved by the scripts with the help of control function for target operating state in MATLAB; the automatic adjustment of parameters in multiple operating modes is achieved by the different initialization parameter requirements for the model in the different operating conditions when switching among different operating conditions selected in the retractable training, where these initialization parameters do not need to be assigned by the operator when the operating conditions are switched, and can be automatically adjusted with the help of control function for system initialization in MATLAB; the allocation and scheduling of parallel computing tasks is achieved by the pre-evaluated of CPU usage of each extension simulation model,
which is combined with the computing resources of CPU board, thereby ensuring the rationality of multi-core computing task allocation. The calculation task allocation diagram can be seen in figure 3.

![Diagram](image)

**Figure 1.** Mechatronic system simulation architecture.

![Diagram](image)

**Figure 2.** The data flow of scheduling module.
2.2. Fault Injection Module
The fault injection module is composed of fault code, fault element model and fault output. The designer and the field commissioner jointly propose faults with a high equipment failure rate and a numbered list of faults that are likely to affect the working process of the equipment. When a fault needs to be injected into the target component, the control system of simulation training process sets the corresponding fault code and transmits it to the fault injection module through the network. The fault injection module injects the corresponding error into the extension model through the simulation of the fault model, and the fault control signal is superimposed on the control signal provided by the analog program control unit to complete the fault injection function.

2.3. Mechanical Simulation Module
The mechanical simulation module includes a simulation model with normal/emergency working mode based on the hydraulic schematic diagram and the mechanical model, where the main body of the hydraulic model is established by the compression chamber method, and the mechanical model is established based on Newton’s law.

The simulation model with normal/emergency working mode mainly provides the signals form pressure sensor, pressure relay, speed sensor for other functional modules of mechatronic system. The internal software framework and data flow diagram for the simulation model with normal/emergency working mode are shown in figure 4, where the local area network is used to exchange the data of simulation model with normal/emergency working mode through the signal communication and other units of auxiliary training cabinet; the internal CPCI bus-fault injection unit refers to the fault injection module located at the fault injection board inside mechatronic simulation unit, and the fault message can be transmitted to the corresponding components of simulation model through the CPCI bus; the load simulation unit is also connected to the simulation model through the CPCI bus to provide the load characteristic signals required by the simulation process; the double hollow arrows on the right indicate that the simulation model with the normal/emergency working mode transmits the internal pressure, flow, speed, angular velocity and other analog signals to the local area network to support the normal operation of other parts in the mechatronic system.

Inside the simulation model with normal/emergency working mode, the modular modeling methods are used to model the various types of hydraulic components and important mechanical structures with regard to the equipment hydraulic schematic diagram and mechanical structure. Among them, the characteristic parameters of the mechanical part, such as mass, moment of inertia, length, angle, and relative position of important mechanisms are read according to the mechanical structure; the damping and friction coefficients are obtained according to the obtained test data or experience; the working characteristics of the solenoid valve, balancing valve, hydraulic motor, and some manual control valves in the hydraulic part are obtained according to the component sample curve, and some valves are also modeled using proportional relationships according to the actual needs.
2.4. Load Simulation Module
The load simulation module is used to simulate the load part that has a large impact on the real-time simulation efficiency, including the friction force of the mechanical contact part and collision part, and the load fluctuation caused by the load swing. In such cases, the force applied to the mechanical contact part is similar to the impact response when a contact collision occurs, where the load swing has a large uncertainty. Therefore, the serial connection method is not suitable in the simulation model, and these load forces are superimposed in dynamics equations of mechatronic system in parallel as the load disturbance inputs. Since such loads always exist in each extension, an FPGA board-assisted computing solution with strong parallel computing capability, short single-step computing time, and less CPU deployment resources is used to complete this function.

3. The Motion Simulation of Mechatronic System
In order to realize the movement of mechatronic system in the simulation, the C# language is used for programming in the UNITY 3D environment, where the scripts with multiple equipment motion are designed. The motion simulation framework of mechatronic system is shown in figure 5.

3.1. The Equipment Motion Simulation Module
In order to show the motion effect of the virtual 3D device during the training process, it is required that the equipment motion simulation should rely on the relative motion parameters (linear and rotational motion speed) of the motion actuator outputted by the mechatronic system, and simulates the motion effects of the actuator and all mechanical parts driven directly and indirectly by the actuator.

In this section, a simulation platform with physical effects is designed with the combination of actual 3D model and built-in PhysX physics engine in Unity3D environment, which mainly implements the collision detection and rigid body dynamic simulation based on the law of conservation of momentum, collision detection algorithms, and collision response processing mechanisms. The real-time simulation of motion is achieved by C# script programming and binding with virtual equipment parts.

The overall process of equipment motion simulation is shown in figure 6, which is mainly divided into the pre-processing and real-time simulation parts. In the pre-processing part, the actual 3D model is defined by mechanical constraints, rigid body, material properties, and motion relationships; In the real-time simulation part, the motion effects of virtual components are simulated based on the actuator motion parameters provided by the real-time simulation of mechatronic system.
3.2. Real-time Guarantee Methods for Equipment Motion Simulation

The real-time of equipment motion simulation has a great impact on its motion simulation effect. In order to guarantee the real-time of simulation process, the following methods are comprehensively adopted:

- **Method 1: Levels of Detail (LOD) technology.** Different strategies are used for 3D rendering according to the position and level of the object in the observation angle, which provide rich display
details for eyesight-focused areas, and simplify the surface structure of objects for edges and distant objects.

Method 2: Parallel simulation technology. Adjust the simulation task during motion simulation so that the CPU and GPU can work cooperatively.

Method 3: Distributed simulation technology. Arrange the physical simulation of models and 3D visual scene on different computers, and the real-time synchronization of status information can be achieved by the network communication, which allows multiple computing and processing equipment to implement simulation simultaneously.

Method 4: Batch processing technology. For the simulation of motion attitude and position of the equipment, multiple independent batch processing tasks are set to be executed cyclically to improve the speed of the simulation, and the simulation process of the virtual model is optimized, which focuses on processing simulation tasks at key locations, simplify the simulation process of some auxiliary non-critical locations, reasonably allocate CPU resources, and can improve simulation efficiency.

4. Video Surveillance Simulation and Interface Design of Mechatronic System

4.1. The Video Surveillance Simulation
In the video surveillance subsystem, the multi-channel video images and dynamic video adjustment methods are combined to obtain high-quality images from multiple perspectives, and provide a useful visual display for operators in the training process.

The detailed process of video surveillance subsystem is shown in figure 7. There are three main display modes of video unit: single-screen enlarged display, all-frame thumbnail display, dynamic following display (one channel is enlarged, and the remaining channels are reduced). According to the message sent by the video surveillance subsystem of current training model, a suitable method can be selected to construct a display screen for the operators.

![Figure 7](image)

**Figure 7.** The process of video surveillance subsystem.

4.2. The Interface Design
The example of a mechatronic system simulation interface is designed in this section, as shown in figure 8, which includes the multi-channel video images to show the equipment from a different perspective, the working mode and fault message to show whether the equipment is running normally, and the motion parameters of equipment in the training process. With the built-in PhysX physics engine in Unity3D environment, the Levels of Detail technology, the parallel simulation technology, the distributed simulation technology and the batch processing technology, this interface has a more realistic motion effect, and has better real-time performance, which can help operators master the use of large-scale mechatronic equipment in a short time with virtual reality technology.
5. Conclusion
In this paper, a mechatronic system simulation method is proposed for operators to master the use of large-scale mechatronic equipment in a short time with the help of virtual reality technology. The real-time simulation of virtual mechatronic system is achieved by the task scheduling, fault injection, mechatronic system and load simulation, where the Levels of Detail (LOD) technology, parallel simulation technology and batch processing technology are used to further optimize the system scheduling time. With the combination of multi-channel video images and dynamic video adjustment, a suitable way to construct the display screen can be selected, and the operator can complete the training with a better perspective, which achieves the purpose of virtual training. Finally, the example of a mechatronic system simulation interface is implemented to verify the effectiveness of the simulation method, which can provide useful reference for the subsequent virtual training platform design of large-scale mechatronic system.

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