A Survey of the Virtual Rebuilding of Manufacturing Process Based on Virtual and Reality Technologies

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Abstract—**Traditional patterns of manufacturing training have a lot of problems, such as high cost, low efficiency and so on. Simulative training for producers based on virtual reality and human-computer interaction, is one of the most economical methods at present. This paper proposes the virtual rebuilding of manufacturing process based on virtual and reality technologies, analyses its status quo at home and abroad, and introduces its key technologies and algorithms, including the simulation object modeling, virtual scene production, human-computer interaction, production process simulation and the simulation result assessment. At last, it makes the summary and looks forward to the future.**

Keywords-virtual reality; human-computer interaction (HCI); simulation

I. INTRODUCTION

The traditional pattern of production training has a lot of problems. For some new equipment with exorbitant prices, complexity structure, wide varieties and limited number, we can't input a large number of practical equipment to train production staff and maintenance. And it usually proceeds with actual equipment and site, which costs a large of tools, parts and materials. It's one of the most economic, fastest and most effective methods to use human-computer interaction (HCI) techniques combined with virtuality and reality.

Since the 1960s, the technology has developed fast, and computer technique has been put into use. It powers the study and application of human-computer interaction. Especially in recent years, with computer software and hardware technology changing quickly, technologies such as computer graphics, computer aided design, virtual reality, artificial intelligence and so on, have gone further in the development. It provides powerful supports to put HCI into use. The application of HCI in manufacturing creates a series applied technologies, such as virtual manufacturing, virtual assembly, virtual maintenance and so on. This article illustrates the virtual rebuilding of manufacring process based on virtual and reality technologies comprehensively from three parts, which contains the current situation of the research at home and abroad, the key technologies and algorithms, and development tendency.

II. CURRENT SITUATION OF THE RESEARCH AT HOME AND ABROAD

The research for this subject originates from the urgent needs for production and maintenance operators in the research of large and complicated systems, which are like airports. This technology takes full advantage of virtual reality to create a vivid training environment, and uses computer simulation technology to reconstruct the operation behavior and the real-time reflection of the equipment in manufacturing, so as to provide intuitional and believable knowledge to trainee, give them a full range of training, and make them get the experience which can't be acquired in reality. This technology is especially applied to high risk industry, such as electricity, nuclear power, weapons and aviation, because of their complex equipment systems and expensive equipment production and the maintenance training for staff. It will improve staffs' qualities, business abilities and work efficiency in seconds. And it has enormous economic and social significance [1]. The technologies are related to it contain virtual maintenance, virtual assembly, etc. Those technologies attract wide attention in industry and academia. People have not only published a large of academic works in the journals and conferences like Computers & Graphics, RAMS (the annual reliability and maintainability symposium), but also launched some commercial software platforms like Jack and DELMIA [1].

V-REALISM, the maintenance training system developed by Nan Yang Technological University in Singapore, was based on the desktop virtual environment, adopted object-oriented ideas, and was built with low cost. The system didn't relate to the application of human model in training, but focused on programming and demonstration of maintenance path. The layout of the user interface provided a good learning environment and convenient operation for trainees [2].

Demis Corvaglia used VRML/X3D, the second Web3D technical language to realize the virtual training of rocket engine's maintenance process in the web browser. It could take full advantage of the existing network technology, and satisfy many people real-time on-line use without additional configuration [3].

Andrea expanded functions of VIR steperson system, which was developed by Italian aerospace center virtual reality lab for the maintenance training of aerospace industrial products. He also added the haptic interfaces, and took full advantage of the existing helmet tracker, data glove and immersive force feedback system. It was not just a workflow demo on visual level when trainees were in virtual maintenance operation. What's more, it could truly experience the dynamic stress of maintenance tools and components, and thereby increasing the

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operation feel and avoiding the damage of precision components which was caused by dynamics' unmerited grasp [4].

In current, virtual simulation platforms, which are mainly the DELMIA of Dassault Systemes company and the Jack of UGS company, have been used widely. Lockheed Martin company uses DELMIA to emulate the process of engine disassembling and weapon reloading in the projects [5-6]. Bombardier company selected Jack to simulate the assembly and maintenance of airborne equipment [7].

Foreign studies in this field has been more and more mature gradually, as well as the domestic researches. VDVAS (virtual design and virtual assembly system), which was developed by Wan Huagen in Zhejiang University, integrated virtual design and virtual assembly. People could use 3D operation and the voice commands in a uniform virtual environment to build components and assembly models, and get the assembling sequence and path. Modeling technology based on constraints would not only recognize and finish the assembly by constraints, but also remove dynamic constraint to realize the disassembly process [8].

Hao Jianping and others in Journal of Ordnance Engineering College used two methods, which contained immersive and non-immersive, to realize the maintenance process simulation, propose a whole project of virtual maintenance system, and re-develop VMSAS (virtual maintenance simulation based maintain ability analysis system) which was based on Jack platform. That system was made up of interface layer, application layer, object layer and technical supporting layer. It contained the creation of the virtual prototype, maintenance simulation, the maintainability analysis and evaluation, system management and other functional modules, and realize functions of building or maintaining task prototype, movement simulation, task simulation, trouble analysis, estimation of remove time and so on [9-10].

Lv Chuan and others in BUAA (Beijing University of Aeronautics and Astronautics) proposed a method and structure of hybird control to increase the efficiency of maintenance simulation. It also meant that it inserted virtual peripherals control mode when the algorithm controlled the virtual human so as to take full advantage of those two control methods and overcome their own limitations[11].

III. KEY TECHNOLOGY AND RELATED ALGORITHM STUDY

From the analysis and summary of recent documents in this field, we can know its research contents mainly include the simulation object modeling, virtual scene production, human-computer interaction, production process simulation and the simulation result assessment. Therefrom, the production process reappearance with the combination of virtual and reality relates a series of key technologies. Below is the introduce.

A. the Simulation Object Modeling

The simulation object modeling contains four steps: geometric modeling, physical modeling, interactive behavior modeling and model testing. We can use 3D CAD softwares such as Pro/E, CATIA or 3D visual modeling softwares such as 3dmax, maya to proceed geometric model; use the method which is based on the event driven or Agent to go on behavior modeling.

The difficult point of simulation object model is physical modeling. Virtual prototype should be able to express the physical properties of equipment component effectively, such as mass, inertia, speed, acceleration and so on. Now there are good solutions for the physical modeling of rigid parts. But for common flexible objects like cable, it still has trouble computing and applying [12]. Literature 13 gives a frame of rigid part's physical properties. It defines three most basic physical concepts in physics, which are time, space and mass, gives the special simulation process of setting physical models of virtual maintenance prototype by obtaining model's geometrical data, realizing physical model's algorithm and simulation, and applies the method to set the rigid parts' model of a large virtual prototype model.

Interactive behavior model is used to describe the motion and action of prototype when interacting human and computer in simulation. Kallmann used the way of feature modeling to define the smart objects based on interactivity, whose action was organized as a project. But the action of the smart object is constrained by state, and it was not suitable for the action based on event driver. Hao Jianping and others carried on Kallmann's thoughts on modeling, divided interactive features into four categories, which were object properties, maintenance features, object action and partial action of virtual body. They saw the state constraint and event driver as the conditions of object action, and related it with object action. The expansibility and reusability of that model was high, and its application scope was wider [15-16].

B. Virtual Scene Production

3D virtual field is made up by loading the 3D models. Its source mainly includes: (1) models directly created by existing CAD system; (2) 3D models created by scenery modeling system. Modeling by CAD system contains a large of information about assembly, component's surface properties and constraints among them. It will lead to oversize data in models, and can't satisfy the real-time interactive demand in 3D scene. Meanwhile, for modeling by scenery modeling system, its output formats are legion and difficult to unify, and the expressing fitness of the effect is also different, so it can't satisfy the need, too. Therefore, it has become the research hotspot nowadays for how to transform existing 3D models into the storage format which is suitable for real-time rendering like .flt and .wrl, especially for how to set a standard 3D model transformation interface. Literature 17 researches atmosphere scatters algorithm, and gets a high emulational virtual earth scene by GPU programming.

With the increasing complex virtual scene, it has become an important problem to ensure the smooth running of drawing procedures. Current solution mainly includes scene division, culling technique, real-time rendering technology based on image, LOD algorithm, parallel rendering technology and other accelerate rendering algorithms.

Literature 18 discusses the fundamental of LOD technology. It analyses some frequently-used LOD algorithms, studies VDPM, and makes great improvement on it. The core ideology of VDPM is to represent a random grid with a greatly simplified grid and a series of relevant records. It will get the original grids and grids on any detail level, and realize that using different LOD for different districts, which is called model's multi-resolution display. That algorithm can be divided into mesh simplification and selective refinement. Mesh simplification decreases the amount of vertexes and triangles of the model by merging the sides constantly, so as to reduce the precision of the model. Selective refinement refines or roughens grids constantly according to the change of the view, so as to get the multi-resolution display related to view. When rendering large scale terrain real-timely, that algorithm has a better real-time show.

In recent years, GPU develops fast, and has powerful collateral processing ability and large memory bandwidth. Its calculated performance has been far beyond CPU. Especially the appearance of CUDA, hastens the development of parallel rendering algorithm in complex scene based on GPU, and it's one of the important ways to solve the problem.

Literature 19 presents algorithms for evaluating and performing modeling operations on NURBS surfaces using the programmable fragment processor on the Graphics Processing Unit (GPU). It extends the GPU-based NURBS evaluator that evaluates NURBS surfaces to compute exact normals for either standard or rational B-spline surfaces for use in rendering and geometric modeling. .All the calculations are build on GPU, and are used to perform standard modeling operations, such as inverse evaluations, ray intersections, and surface-surface intersections on the GPU. The GPU-accelerated algorithm to perform surface-surface intersection operations with NURBS surfaces can output intersection curves in the model space as well as in the parametric spaces of both the intersecting surfaces at interactive rates.

Based on the description of the literature above, when we model the virtual maintenance scene, we can build the 3D field with CAD, and use GPU-based LOD algorithm or real-time drawing technology to speed up drawing rate.

C. Human-Computer Interaction

In the process of virtual training, trainees carry on corresponding operations in virtual scene to finish the training. The main technologies are collision detection, precise positioning and gesture recognition.

1) Collision Detection: Collision detection is the base to realize HCI in virtual simulation system. Now collision detection algorithms include: 1) the space partitioning which is based on spatial data structure like BSP and octree; 2) algorithms based on bounding sphere, bounding box, OBB and others; 3) algorithms based on Lin-Canny; 4) algorithms based on sweep and cliping; 5) GJK algorithm; 6) algorithms based on distance field and random algorithms. Nowadays, the first three algorithms are more developed. Through the calculation of object's bounding box and the establishment of bounding box tree, literature 20 sets the level of expression of the objects, and traverse two bounding box trees to have an overlap test of bounding box, and thus the overlap test of basic geometric elements, and finally determines whether the two objects sre intersected. The algorithm is simple to understand, and you can solve the collision between the concave polyhedrons.

With the rapid increases of the graphics hardware performance, image-based collision detection algorithm shows good prospects for development. Govindaraju and others based on CULLIDE algorithm, and raised Quick-CULLIDE algorithm. In the early stages of the collision detection, it used graphics hardware to accelerate the detection process, and quickly removed the obvious disjoint objects, and then had geometric intersection tests in the detection, unlike the other image-based collision tests that used graphics hardware in the test. Compared with CULLIDE algorithm, there was a substantial increase in efficiency [21]. For the shortcomings that when drawing complex large-scale 3D scene, collision detection would take up a lot of the system resources.

2) Gesture Recognition: Gestures' inherent naturality, richness and directness, make it one of the main means of HCI. Users can define the gesture trigger command to control the objects or events in virtual scene. The two most commonly used natural gesture input methods are based on the data glove and based on the computer vision. From the point of view of pattern recognition, both use the same method to identify.

Data glove-based gesture recognition frequently uses neural network. The method that is applied to the static gesture recognition has been the case. Literature 22 uses fuzzy neural network technology to achieve the recognition of maintenance operations gesture, and to establish interactive control mechanism based on the virtual hand gesture recognition. But the limited capacity of neural networks in time series modeling and the large in training computation, it is difficult to become a mainstream method of dynamic gesture recognition.

Vision-based gesture input has fewer restrictions on the movement, and it's the current research focus. In 2010, the somatosensory gaming device — Kinect, which was launched by Microsoft, led to a revolution in HCI. It is a 3D somatosensory camera, and has real-time motion capture, image recognition, microphone input, voice recognition, community interaction and other functions. In action recognition, Kinect uses 3D depth camera technology, and gets the 3D depth information of the image with the use of infrared sensors. From this information, we can get the human spatial location and the location of the main bones, which can capture people's movements. In gesture recognition, it has been a great success. Literature 23 provided an application with no major dependencies of the work environment, lighting or users' skin color. In this application, libraries of particular used for natural interaction and Kinect device, which serves to provide RGB images of the environment and the depth map of the scene were used. The user was allowed to perform manipulation of virtual objects.

3) Precise Positioning: The precise positioning of parts in the virtual environment is to ensure that the parts can be assembled in accordance with their relative positions as a prerequisite of the assembly. In the virtual assembly process, trainees manipulate installed parts by interactive devices like 3D mouse and data glove. These movements with ambiguity and imprecision, lead to the result that it's difficult for trainees to assemble the parts precisely in place.

In the actual assembly environment, people guide the parts movement through the synergy of visual and tactile, in order to achieve accurate positioning of parts movement. In a virtual environment, due to the limitations of current technology, achieving the guidance of the parts movement by touch sensor to get the precise assembly of the parts is less likely. Current positioning methods include the precise positioning based on geometric constraints automatic identification, precise positioning based on interactive constraint definition, and components' directly precise positioning based on the target location.

Jayaram and others in Washington State University [24], first proposed to use the assembly constraint information, with the parts constrained movement and constraints, to achieve the precise positioning of the parts in the virtual assembly process. However, the method requires that the assembly constraint relationship in the product assembly and the traditional 3D CAD system should be fully consistent. It's often difficult to do in the actual engineering application.

Interactive constraint is defined as a complement to the collection of the automatic identification of constraints. With this method, it can be faster to determine the constraint relations between the parts in the situations that the structure of parts is complex and the geometric elements are many. Interactive constraint definition inherits mode in which the assembly constraint is defined by current commercial CAD systems, and constraint relations between two parts are defined by users in HCI. Its process is mainly reflected in the pick up on the formation of the elements of the geometric surface. After picking up a patch on the object, the system will be based on the mapping between the geometric surface elements and patches defined in the virtual assembly model, and pick up the needed geometric surface elements via the patch to query the corresponding geometric surface elements [25].

The location restraint is a supplementary for automatic identification of geometric constraint. In the virtual assembly process, when users move the parts which are going to be loaded to the vicinity of the target mounting position, they can quickly assemble the parts in place by directly precise positioning based on the target location as required.

Literature 26 uses the components precise positioning mixed with automatic identification of geometric constraints, interactive constraint definition and location constraints. It's implemented in its self-developed virtual assembly process planning software VAPP.

4) Production Procee Simulation: Production process simulation generally installs or removes a product by real or virtual people in virtual scene. The interaction is real-timely tracked and recorded, in order to get the order of the disassembly, disassembly path, tools, methods of operation, time and other process information. Modeling the production process, we can make an overall planning on the work and deployment of resources from a high level. It's the core technology of maintenance simulation system for complex equipment. The common modeling methods include UML, PERT, Petri nets and others. Among them, because Petri nets is intuitive and easy to understand and use, and has a mathematical analysis capabilities which are defined strictly, it's a powerful modeling tool in virtual maintenance process. Based on the inverse of the assembly and decomposition of Petri nets, Zussman and others proposed an adaptive planning approach. It determined the demolition order through the dynamic allocation of priority, and made the system automatically adjust the demolition process according to the changes in the success rate of demolition [27]. He Jianbin, using colored and time Petri nets, and guiding the concept of object, built a maintenance process model to reflect the competition for resources, concurrency and synchronization in the process of maintenance operations [28].

In the virtual simulation system of maintenance, when disassembling the virtual equipment, its sequence is determined by user's senses and experience, with a certain degree of blindness and uncertainly. At that time, we need to learn from a number of disassembly sequence generation method for continuous improvement and fusion to seek the best disassembly sequence of devices. Nowadays, the common sequence generation methods include the law on the statute, the precedence constraint method, the knowledge-based solution method and genetic algorithm. The disassembly sequence generated by these methods has a high correctness, and a certain intelligence. PRM, which is proposed by Overmars, is the main algorithm for disassembly path planning. Srinivasan, etc. proposed hierarchical map and virtual demolition metrics, and on this basis, based on genetic algorithm, they proposed a wave propagation disassembly sequence optimization algorithm for the selective demolition, to solve the minimum disassembly sequence [29]. For the limitations that the number of connective subgraphs in Roadmap is large and the efficiency of the visibility judgement is low in PRM and Visibility-PRM algorithms, based on the sampling of obstacle boundary and new sample point connection policy, Xuan Jun, etc. built the Obs-Vis-iPRM algorithm by setting the threshold of visibility judgement. It reduced the number of the connective subgraphs in Roadmap, greatly decreased the number of collision detection and improved the efficiency of the algorithm [30].

5) the Simulation Result Assessment: In the system of simulation production training, the training evaluation modules should give a quantitative evaluation or grading satisfaction appraisal objectively for operating process, so as to arouse trainees' learning desire, which is an important part in the process. Current assessment methods include list scoring, weight function, expertise, neural network and others. Whatever we use, its foundation is to create expert system knowledge base, and system developers need to understand the right business process in deep.

IV. SUMMARIZE

This paper briefly describes the research states and technique process of the technology, namely, the virtual rebuilding of manufacturing process based on virtual and reality technologies. And it also introduces some related algorithms and principles to make people understand more about it. Current programming languages include what used for the graphics workstations or high-performance computers like

OpenGL and Direct, ones oriented web dimensional virtual simulation like VRML and Java3D, Kinect-based OpenNI and others. With the deep study on computer technologies like HCI and PR, this technology will be more perfect, and its applied range can also extend from machinofacture to more. Its application and prospect is very promising.

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