■   4282

Virtual Training System for Hydraulic Pump Cart based on Virtual Reality

Wusha Huang, Qiang Chen*, Minzhuo Wang, Haonan Ye
Department of System and Control Engineering, Nanjing University
No. 22 Hankou Road, Gulou District, Nanjing, China
*Corresponding author, email: huangwusha1987@163.com[1], chenqia0772@vip.sina.com[2],
njuwangminzhuo@gmail.com[3], echodarkness@sina.cn[4]

Abstract

This paper presents the application of Virtual Reality Technology in the training process. Virtual training system has more advantages than traditional training system. The design of virtual training system based on PTC DIVISION Mockup software, position tracker and 3-D mouse is proposed. The system is divided into two parts: directing part and operating part. Collision detection is discussed to improve the sense of reality in the virtual environment .This system is applied to the training process of hydraulic pump cart's assembly and disassembly. More immersive training effect is obtained in this system. The goal of reducing training costs and improving the efficiency of training can be achieved in the virtual training system.

Keywords: virtual reality, virtual training, DIVISION Mockup, collision detection, hydraulic pump cart

1. Introduction

The virtual reality (VR) technology is regarded as a natural extension to 3D computer graphics with advanced input and output devices [1]. It has the features of immersion, interaction and imagination [2]. By means of the high-tech peripherals and computer software, users can experience multi-perceptual and real-time human-computer interaction, just like in the real world. As an important application of VR, virtual training system is widely used in aerospace, military, manufacture, engineering and other fields [3-6].

In traditional training mode, trainers and trainees need to be in a specific circumstance and make face-to-face contact. This training mode lacks of individuality. Since trainees have different learning capacities, it is time-wasting for someone, while it isn't enough for others. So there may more or less exist the wasting of manpower, resources, time and funds. When training is dangerous or the training equipment is inaccessible, this mode is difficult to achieve the training effect. Therefore, the traditional training mode has limitations and it can hardly meet the needs of our modern society [7].

As a new type of training method, virtual training mode combines the advantages of VR with training [8]. It provides trainees with multi-perception such as visual, voice, feelings etc, in order to immerse trainees in a certain virtual training environment. This mode can solve the problem of theory and practice in the training process. Before facing the real equipment, trainees can be trained to be familiar with the environment, components and the operation procedure. According to trainees' own condition, they can choose repetitive training on diffident parts so as to be skillful in manipulating. Virtual training can overcome the shortcomings in traditional training. The damage to the trainees or equipment which results from incorrect manipulation can be avoided. Virtual training mode can greatly shorten the training time, improve training speed and quality, decrease cost and reduce training risk.

In this paper, a virtual training system based on DIVISION Mockup software, position tracker and 3-D mouse is proposed. And collision detection of this training system is discussed. Trainees can get comprehensive knowledge of hydraulic pump cart by Functional Simulation structure in DIVISION Mockup. Also they can manipulate the virtual equipment through position tracker and 3-D mouse. Immersive, safe, efficient, resource-saving and individual training effect can be obtained in this system.

2. System Design

Virtual training system is based on VR technology. According to actual task, a training system with friendly interface, good sense of reality, and practicability is expected to be established. Trainees firstly learn the comprehensive knowledge of the equipment. Then the standard and skills of the operation procedure can be mastered by repeating operation based on the guidance. According to the requests mentioned above, the virtual training system is divided into two parts, one for directing and the other for operating. Figure 1 shows the two parts and their functions.
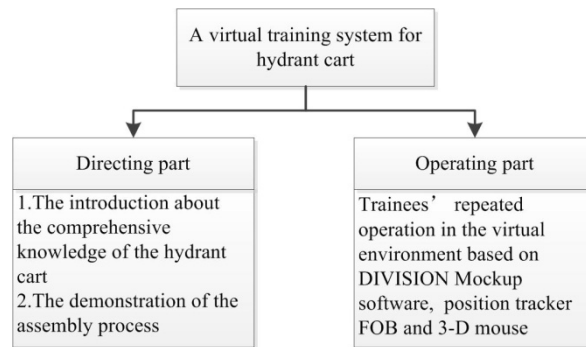

Figure 1. Two Parts of the Virtual Training System

The hierarchy of the system can be described as Figure 2. There are four layers: VR hardware layer, VR hardware driver layer, world management layer and application layer.
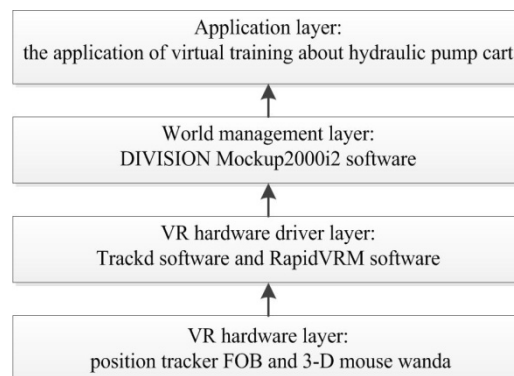

Figure 2. Hierarchical Structure of the Training System

DIVISION Mockup software is applied in the virtual training system. In order to make the model of the hydraulic pump cart lifelike and easy to browse, the landmark scenes, light, virtual material and the behavior property are set up in the DIVISION Mockup software. The movement simulation of hydraulic pump cart is completed by Functional Simulation. By using a variety of peripheral equipment, such as Flock of Birds (FOB), 3-D mouse and stereo glasses, the interaction between the trainees and model can be realized

3. Implementation of the System
3.1. Implementation of the Directing Part.

The goal of the directing part is to introduce comprehensive knowledge of the hydraulic pump cart livingly and to guide the trainees through the overall assembly process as they are on the real scene.

After the virtual prototype converted to the DIVISION Mockup software, it is feasible to create parts' assembly or disassembly sequences to realize the above-mentioned functions. But it is much better to make use of the Functional Simulation than the Sequences. Because the Functional Simulation can not only achieve more simple and precise positioning and timing of the elements' movement, but also get better human-computer interaction. Functional Simulation is composed of many behavior properties [9]. Before setting the movement simulations, all action parameters of the elements must be defined. More accurate positioning and timing can be got in the virtual environment.

In the directing part of the virtual training system, there are eleven main behaviors which contain the introduction and guidance of the hydraulic pump cart. Each behavior is composed of a multiple event. Each event is consisted of lots of actions. Every event can trigger many actions, which may send other events to trigger other actions in turn. As a result, a very complex combination of behaviors can be simply added to a virtual part. The component of the "OpenDoors" behavior is shown as Figure 3.
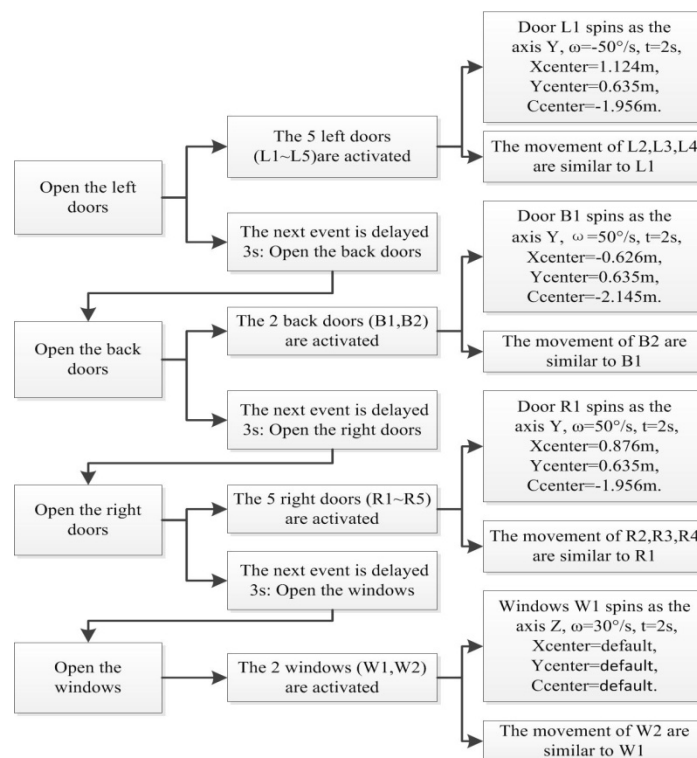

Figure 3. "OpenDoors" Behavior

The "OpenDoors" behavior is composed of four behaviors. They are linked by the delayed events. The rotation, action time and remaining action parameters are pre-defined in each part. These actions are activated by the Activate events. The other ten behaviors are composed in the similar way as the "OpenDoors" behavior. These behaviors are attached to eleven buttons in the virtual environment. Instead of pitching on the "Send Event" from the Edit pull-down menu of DIVISION Mockup, trainees can simply click on buttons in the virtual environment by 3-D mouse and FOB, to get better details of the hydraulic pump cart. The interaction in the virtual training system is more friendly and convenient

3.2. Implementation of the Operating Part

After getting familiar with the knowledge of the hydraulic pump cart and its assembly process, trainees can assemble or disassemble virtual parts with the peripherals in the virtual environment. The composition of the operating part is shown as Figure 4.
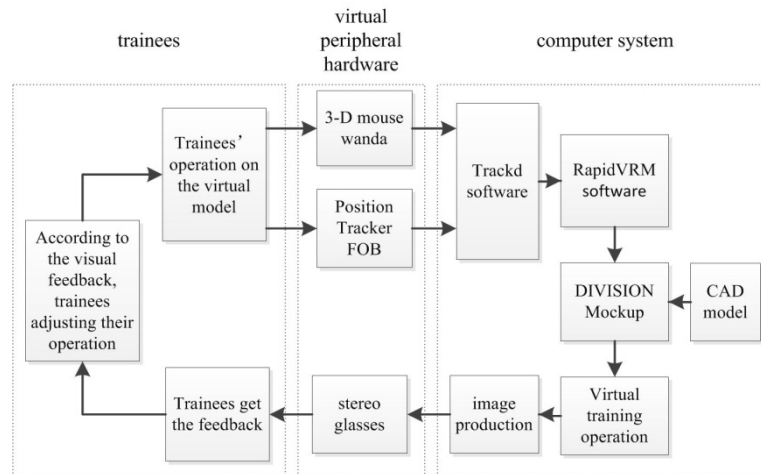
Figure 4. Framework of the Virtual Training System

Since the virtual training system is a combination of software (DIVISION Mockup) and peripheral hardware (position tracker FOB, 3-D mouse), it is important to integrate them seamlessly. By virtue of the Trackd software and RapidVRM software, the peripheral hardware and DIVISION Mockup can be cooperated well.

The FOB is a six degree-of-freedom measuring device. It can be configured to track the position and orientation of up to thirty sensors by a transmitter simultaneously. It determines position and orientation by transmitting a pulsed DC magnetic field that is simultaneously measured by all sensors in the Flock. In the virtual training system, a sensor is attached to the 3-D mouse to track its position and orientation.

The hardware connections must be completed at the beginning. The rules of interface between FOB, 3-D mouse and the computer system are described below.

1. FOB is connected to the computer's COM2 port via its RS-232 interface.
2. The status of the FOB's DIP SWITCH is shown in Table 1.

Table 1. Status of the FOB's DIP SWITCH

Dipswitches	1	2	3	4	5	6	7	8
status	on	off	on	off	off	off	on	off

3. Sensor is attached to the FOB through the labeled 'XMTR' interface on the front panel of the Bird electronics unit. 3-D mouse wanda is connected to the computer's COM3 port via another RS-232 interface.

Trackd software is used to interface to several tracking and controller devices [10]. It receives data from trackers and input devices, and makes it available to immersive display applications via shared memory. So particular work rules for certain trackers and input devices need to be set in the "trackd.conf" file which defines each peripheral's name, port, data transfer rate and shared memory address etc. The configuration file for the virtual training system is described below.

```
DefineDevice FOB fobirds 1        //the peripheral's name is FOB
DeviceOption FOB port com2        //FOB is connected to the computer via com2 port
DeviceOption FOB baud 38400       //the baud rate is 38400
DefineDevice Work wanda           //the next peripheral's name is wanda
DeviceOption Work port com3       //wanda is connected to the computer via com3
port
DefineConnector Shm1 shm out 1    //define the shared memory, sensor number and
                                  //the direction of data flow
ConnectorOption Shm1 key 4126     //define the mark of the memory address
```

The RapidVRM software is an up-to-the-minute powerful interface that connects with DIVISION Mockup and Trackd. It collects all the signal of motion tracking systems and interaction equipment. The analysis rules of RapidVRM is in the file called "rapidvrm-*.bod" which defines the relations between the motions in DIVISION Mockup and the buttons' definitions in Trackd. The file is shown below.

```
BIND "BUTTON_0" FLY_UP_SLOW
BIND "" FLY_UP_FAST
BIND "" FLY_UP_ACCELERATE
FLY_UP_ACCELERATION 0.075
FLY_UP_SLOW_SPEED 0.1
FLY_UP_FAST_SPEED 4
FLY_UP_MAX_SPEED 8
```

The definition of BUTTON_0 in the Trackd software equals the motion of flying up slowly in DIVISION Mockup software. In fact, BUTTON_0 is the first button in the 3-D mouse from the left.

Apart from defining Trackd and RapidVRM, it is necessary to create a .reg file which transfers the information of RapidVRM to the registry. Then, the signal analysis from Trackd and the feedback from the DIVISION Mockup can be achieved.

After completing the cooperation between hardware and software, trainees can operate the virtual product, such as picking, moving, rotating and releasing. By virtue of stereo glasses, trainees can get immersed in the virtual environment. According to the virtual feedback, trainees adjust their operation repeatedly. Finally, trainees are familiar with the hydraulic pump cart and skillful in the assembly or disassembly process.

4. Collision Detection

In the virtual training system, when virtual hand captures the objects, it is required to determine the collision status between the virtual hand and the objects opportunely, which is called collision detection [11]. Real-time and accuracy are two important constraint conditions of collision detection. There are numerous complicated components in the virtual environment. So it is time-consuming to detect their collisions. Because of the high level criterion of system time-consuming, the collision detection should be finished in a very short time. The real-time of collision detection has become bottleneck of the development of virtual training system. If the computing time cost of collision detection is too huge, it is very likely for the system to fail in display fluency enough, such as image lag. The accuracy of the collision detection is also an important index for the virtual training system, which need to calculate the exact position of the collision.

The algorithm frame of collision detection is showed as Figure 5 [12]. When it comes to deal with some complex situations which include a big amount of objects, some objects which do not intersect should be excluded at the first place and detect the objects which may intersect later. This procedure is called preliminary detection stage. All the succeeding stages are called advanced detection stage, which uses the bounding volume hierarchies (BVH) as its collision detection algorithm.
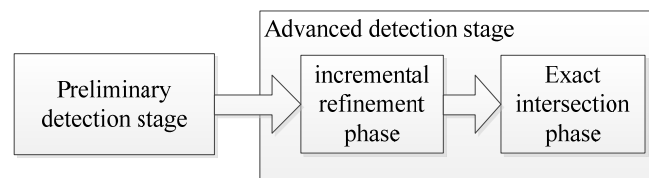

Figure 5. Framework for Collision Detection Algorithm

BVH is an effective solution to the problem of rigid body collision detection. It describes approximately the object with a simpler bounding box that is a litter bigger than the object, and

detects whether there has a collision between bounding box by the level of binary tree traversal, and then continues to do the intersection test to the basic geometry elements inside the box to determine whether there has a collision between objects. The common types of BV are Axis-Aligned Bounding Boxes (AABB), Oriented Bounding Box (OBB), Discrete Orientation Polygons (k-Dops), Fixed direction hulls (FDH) and so on.

AABB is the most widely used method in collision detection research. The AABB of a given object is defined as the minimal hexahedron which includes this object and parallels to the coordinate axis. The calculation of the given object's AABB is very simple. We only need to calculate the maximum and minimum value of the vertexes' X, Y, Z coordinates of the elements which compose the basic geometrical element sets of constituent objects. The intersection detection of AABB is very simple: two AABB intersect with each other if and only if the projective zones of their three-dimension axis overlap. In this article, AABB bounding volume hierarchies is adapted. By adapting a top-down building method of a hierarchy binary tree, we can approach the geometrical properties of the objects.

The collision detection of virtual training system has its own characters. Virtual training system is a closed-loop system which consists of human, computers and its peripheral devices. The input model is dynamic object (virtual hand or virtual component captured by virtual hand) and several static objects (static components). During the detection, the position and pose of the static objects is permanent while the dynamic objects can do free movement in virtual environment according to the instruction of users. In virtual training environment, collision can only happen between the virtual hand or moving components and other units. Only bounding volume (BV) collision detection is necessary in the collision detection of the components without assembling relationship while the surface collision detection is operated between the objects with the assembling relationship [13-15]. Based on the above ideas, the collision detection algorithm is showed in Figure 6.
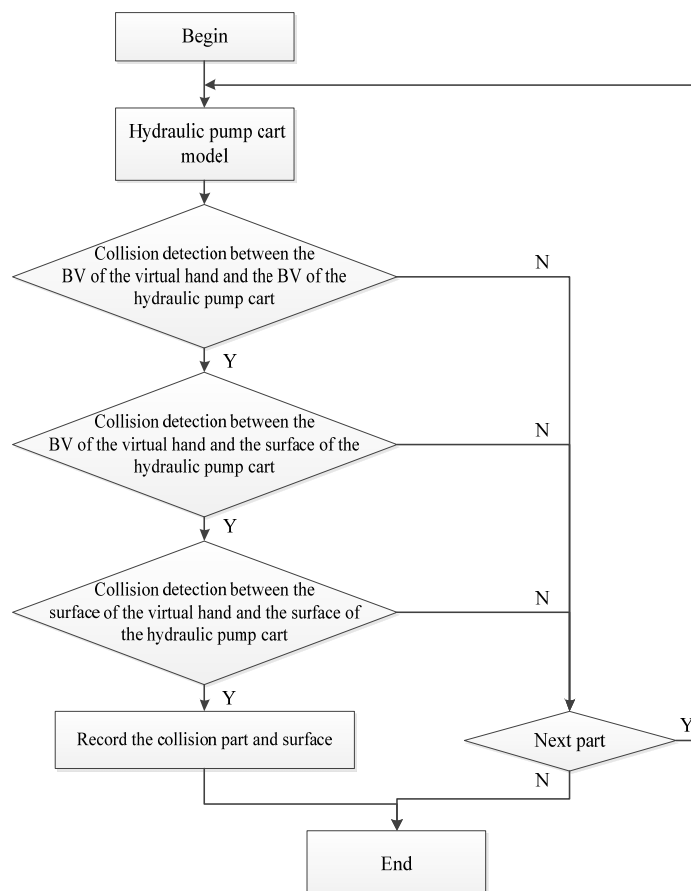

Figure 6. Collision Detection Flow Chart based on Bounding Volume

Virtual hand and objects will be in touch when virtual hand grasps virtual objects. If virtual hand keeps moving forward, it will be penetrate in the virtual objects which will influences the reality sense of the virtual environment. Therefore, how to prevent the penetration between the virtual hand and virtual objects is also a very critical issue of virtual operation.

In order to prevent the virtual hand penetrating through the objects, our traditional solution is backing the virtual hand to its original position. This method will ruin the reality sense of virtual environment. So, we choose the penetration restriction algorithm which based on the surface collision detection [16].

As it showed in Figure 7, virtual hand and triangle surface come to a collision and the touch point is P. The normal direction of the triangle surface in P is n, whose opposite direction is inner part of the object. n_x, n_y, n_z is the projection of n at axis X, Y, Z. If the movement of virtual hand is limited in the hemisphere that consists of n and p, the virtual hand will not penetrate the object. As it is showed in Figure 7, $n_x>0$, $n_y>0$, $n_z<0$, and if the three components of the movement direction of virtual hand are the same as the three corresponding components of n, the virtual hand can move freely. If not, the movement of virtual hand should be limited and the position and pose of virtual hand should be kept as the former status.
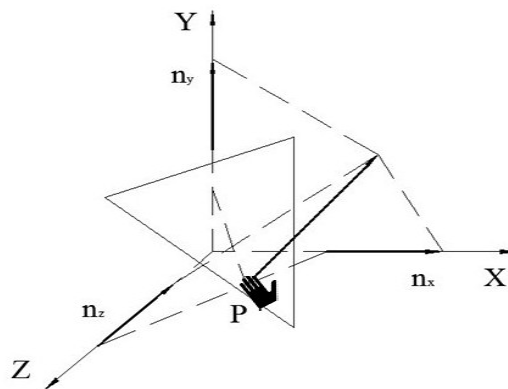

Figure 7. Penetration Restriction of the Virtual Hand

5. Application Example

In the virtual training system, the 3-D model of hydraulic pump cart is set as the training object. Because of the large volume and complex structure of hydraulic pump cart, it is difficult and cumbersome to realize training on real scene. So it is much more effective to implement the virtual training mode rather than the traditional training mode.

In the directing part of the virtual training system, there are eleven behaviors which are attached to eleven buttons respectively to provide friendly interface between trainees and computer system. When touched, each button will trigger relevant behaviors. Take the "DeViewCarBody" button for example. When this button is touched, the body of hydraulic pump cart is hidden. Then the hydraulic pump cart rotates 360 degrees, in order to show the inner structure of the cart.

When the behaviors are activated, the details of each motion are displayed in the view window. The main view window of the directing part is shown in Figure 8.

Under the guidance of the directing part, trainees can assemble or disassemble the elements of the hydraulic pump cart through 3-D mouse and FOB in the operating part. By repeating operation, trainees become more skillful in the manipulation of the hydraulic pump cart.

Some properties of each component must be created in the DIVISION Mockup during the overall procedure, such as Pivots and Constrains. Pivots define the rotation axis. Constrains restrict components' movement in the limited areas. These properties can be used to prevent trainees' incorrect operation. The main view window of the operating part is shown in Figure 9.
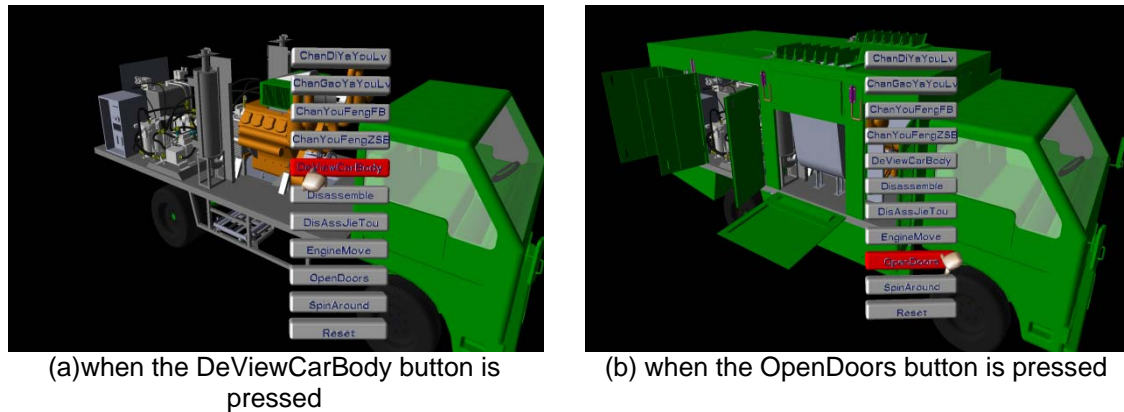
(a)when the DeViewCarBody button is pressed

(b) when the OpenDoors button is pressed

Figure 8. Main View Window of the Directing Part in the Virtual Training System

(a)when the oiltight of the auxiliary pump is changing

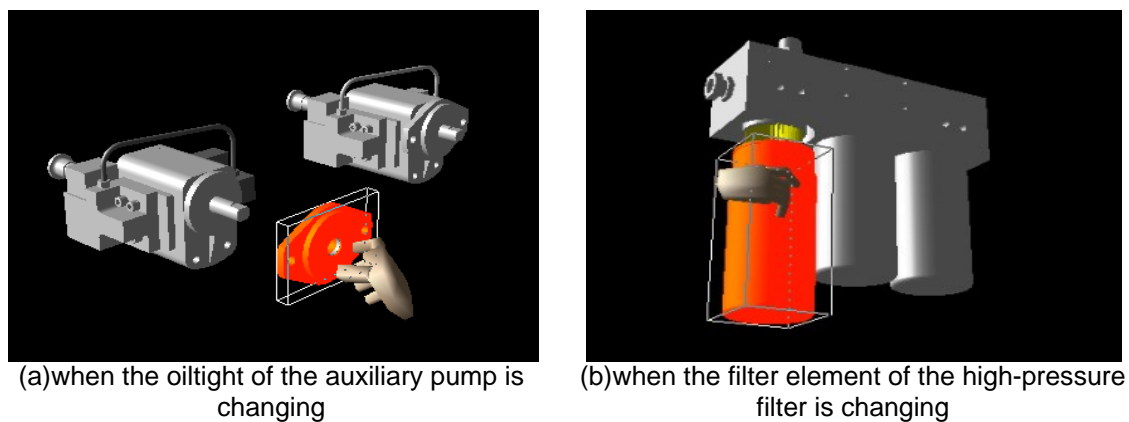(b)when the filter element of the high-pressure filter is changing

Figure 9. The Main View Window of the Operating Part in the Virtual Training System

6. Conclusion

A virtual training system based on DIVISION Mockup software, 3-D mouse wanda and position tracker FOB is implemented. And collision detection of this virtual training system is discussed .The virtual training system provided a friendly interaction between trainees and virtual equipment, and achieved good results. The thought of the system can be popularized to virtual assembly and other applications. It can be worked with data gloves, helmets and other peripherals to provide more immersive and interactive experience. Users can get familiar with the experimental settings, instruments and steps in the virtual environment before facing the real ones. It is particularly suitable for the situation that the operating instruments are complex or the equipment can be hardly accessed. Virtual training can avoid damage or loss, and can improve training efficiency.

References

[1] Yongmin Zhong, Weiyin Ma. Edited by S.K.Ong and A.Y.C.Nee. Virtual and Augmented Reality Applications in Manufacturing. Singapore: Springer Publications. 2003.
[2] Xia Zhao. Virtual Reality Technology Application and Development Trend. *CD Technology*. 2009; 11: 10-12.

[3] Peike Shi, Ming Gao, Gang Huang. A Virtual Training System of Concrete Pump Track. *Information and Intelligentization*. 2010; 41: 2-4.

[4] Liang Ju, Mansi Li, Yong Xie. Equipment Virtual Training System Based on Vega and GL Studio. *Information Technology*. 2010; 6: 113-116.

[5] Suyuan Wei, Chao Ning, Shiying Zhang, Qing Ni.The Aerospace Simulation Training System Based on VRML. *Aerospace Shanghai*. 2003; 1: 31-34.

[6] Guojun Wei, Yuanchang Zhu, Zhijie Wang. The Realization Tech of A Certain Radar Equipment Virtual Training System. *Fire Control and Command Control.* 2006; 12: 74-78.

[7] Wei Cui, Tiegang Xun, Weihua Han. Virtual Training Technique and System Development. *Journal of Chendu University of Information Technology*. 2003; 18: 361-365.

[8] Chunhui Su, Fangting Yang, Ying Tu. The Research and Implementation of Virtual Training System Based on The Data Glove. *Journal of System Simulation*. 2009; 21: 189-192.

[9] Lun Li, Jishun Li, Wei Ma, Yujun Xue, Yonggang Liu. *Virtual Prototype of the Tunnel Boring Machine and Movement Simulation in DIVISION MOCKUP2000i2*. Proceedings of the 6th CIRP-Sponsored International Conference on Digital Enterprise Technology. 2010; 66: 525-532.

[10] Lun Li, Jishun Li, Feng Du and Donghong Si. *Building Virtual Reality Design system Based on DIVISION Mockup Software*. International Conference on Electrical and Control Engineering. China. 2010: 25-27

[11] Guofu Ding, Jinnuo Wang, Xiaojun Zhang. Collision Detection between Virtual Hand and Virtual Parts in VA. *A pplication Research of Computers*. 2003; 20(2): 29-31.

[12] Jie Dai. Research and Application of Collision Detection Technology in Virtual Assembly System. Master Thesis. DaLian JiaoTong University: 2009.

[13] Noborio H, Fukuda S, Arimoto S. Fast Interference Check Method using Octree Representation. *Advanced Robotics.*1989; 3(3): 193-212.

[14] James T Klosowski, Martin Held, Joseph SB. Efficient collision detection using bounding volume hierarchies of k-DOPs. *IEEE Transaction on Visualization and Computer Graphics*. 1998; 4(1): 21-36.

[15] Maruyama K. A procedure to determine intersection between polyhedral object. *International Journal of Computer and Information Science*. 1972; 1(2): 219-242.

[16] Jiangshen Liu, Yingxue Yao, Jianguang Li, Pingjun Xia, Guohua Liu. Virtual Manipulation Based on Data Glove in Virtual Assembly. *Journal of System Simulation.* 2004; 16(8): 1744-1747.