

# Development of PC-based 3D Dynamic Human Interactive Robot Simulator

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## Abstract

PC-based immersion-type display integrated with a motion capture system as well as a 3D dynamic simulator has been successfully constructed in our laboratory, as a first universal development environment of human interactive robot within Japan. This system makes it possible for us to design and examine the next generation of human interactive robot easily and safely. Experiments of a virtual robot interacts with human and performs dynamic motion show the effectiveness of our system.

## 1 Introduction

Unlike industrial robots performing only specific motions in well-structured production lines, recently, development of robots working in general environments such as streets or homes is highly expected, and many researches about such intelligent robots are reported. There are many differences between the industrial robots in the factory and the robot that will play an active part in a general environment. The difference also comes from the basic design approach, the valuation angles, and the experiment techniques, so on. For example, although speed and accuracy of operation are important for the industrial robot, the robot in a home is evaluated based on its affinity and safety. Moreover, the human subjective evaluation of the robot's form, color and feeling are also important. Therefore, when considering the development of human interactive robots, people will be included in a robot's design and experiment environment in a natural way.

By now, there are many robots proposed for human interaction such as pet robot [1, 2] and the robot which communicate with people using a gesture and speech synthesis [3, 4], however, these robot fundamentally does not perform any force interactive tasks and does not exchange large power with people. Experiment of human-robot interaction with large force is very dangerous and has high risk. Although the experiment which uses a dummy doll instead of human being is also considered, the subjective evaluation of the robot cannot be obtained from the target human directly. Moreover, although we want to know what will happen for the robot when human interact with it, the experiment is difficult from the point of view of the robot's durability or cost.

Considering these facts, a general technique performs simulations instead of real experiment and some simulators about a robot are proposed [5, 6, 7]. However, when we consider the development of the human interactive robot, it is not realistic to model the human subjects from the view of the point of the model's accuracy. In addition, the simulation results of a robot were usually

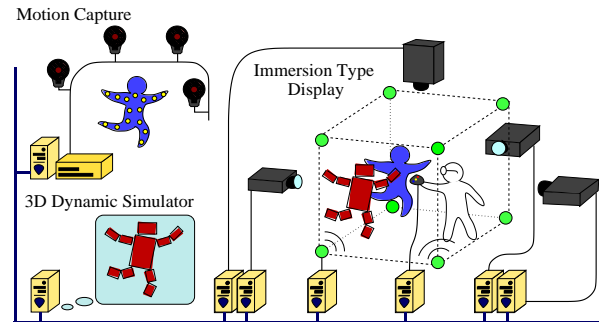


Figure 1: Setup of the proposed system

presented on a PC display and has different size compared with the actual robot. Therefore, the evaluation of the robot's form and color is difficult.

In this research, we construct a novel simulation environment for developing human interaction robot. This system uses AT-clone computers to calculate 3-dimensional dynamics and collision of a robot when it interacts with human and projects the audiovisual results using an immersion type display. Through dynamic calculation of the robot, human can interact with it directly in real time. Based on this robot simulation environment, we can easily design and evaluate the form and performance of the virtual robot with high safety and sufficient accuracy.

## 2 Outlines of our system

As shown in the Figure 1, the robot simulator which we propose consists of three parts. They are:

- (1) an immersion type display,
- (2) a 3-dimensional dynamic simulator, and
- (3) a motion capture part, respectively.

Each part consists of two or more PC computers, and all computers can communicate with each other through TCP/IP.

The immersion type display part present human with audiovisual information and tactile sensation, which makes the human subject feel as if he/she is interacting with the virtual robot directly. For vision display, it is necessary to give the subject the feeling as if he/she is facing an actual robot. For audition on the other hand, the location of the sound source such as the robot's footstep and voice should be set so that the subject can hear where the sound actually comes from. In addition,

when a subject touches the robot, it is necessary to display the force, although it has not realized and is under research now.

The 3-dimensional dynamic simulator part controls a virtual robot to follow the given set of target angles while interacting with human subject. Here, it is necessary for the 3-dimensional dynamic simulator part to consider both the gravity as well as the external force applied to the robot from human in its dynamic calculation. As a result of this calculation, the instruction torque is calculated based on the target angle and the torque added by the subject. The position and orientation of each link are then calculated in real time for every sampling period.

The robot's form here takes a humanoid type, its target joint angle is measured from the motion of an actual human subject by using the motion capture part.

Hereafter, 3, 4, and 5 explain in detail the immersion type display part, 3-dimensional dynamic simulator part, and the motion capture part, respectively. And in 6, experiment examples on application of this simulator is presented. The conclusion is given in 7.

### 3 Immersion type display part

As shown in the Figure 2, the immersion type display part presents the human subjects with high presence of the virtual robot. The visual and auditory information playing an important part for perception are installed in this system. The tactile and force information between the virtual robot and the human subject are also important to realize the effective image projection. Currently, the devices have been developed to display these kinds of information.

#### 3.1 Display of visual information

Immersive Projection Technology (IPT) uses parallel image display system to show the 3-dimensional scenography. The displayed images are projected on the screens arranged as the wall surrounding the human subject. The high resolution of image and a large visual field angle provide a high feeling of immersion to human. Some types of IPT have been reported in the past. For example, CAVE (CAVE Automatic Virtual Environment) [8] has four screens (front, right, left, and platform screen) and CABIN (Computer Augmented Booth for Image Navigation) [9] has the five screens. COSMOS (COsmic Scale Multimedia Of Six-faces) consists of the six screens.

Since conventional IPT is constituted with the expensive supercomputer, it required high cost not only for using it but also for maintenance. We solve this problem by constructing the efficient low cost system using four PC/AT-clone computers to process graphics with high speed. From our experiments, it is found that, although the calculation capability of a PC/AT-clone computer is inferior to an expensive supercomputer, it is possible to cover the lack of performance by reducing the complexity of the displayed contents. Moreover, considering the rapid increase of the calculation and/or drawing capability of PC/AT-clone computer and ease of maintenance, this setup can be used to realize our research objective for simulating human interactive robots. In the following paper, we simply call this projection system "PC-CAVE". PC-CAVE processes and renews the images of a virtual robot by sensing the position and orientation of the human subject's head with the mag-

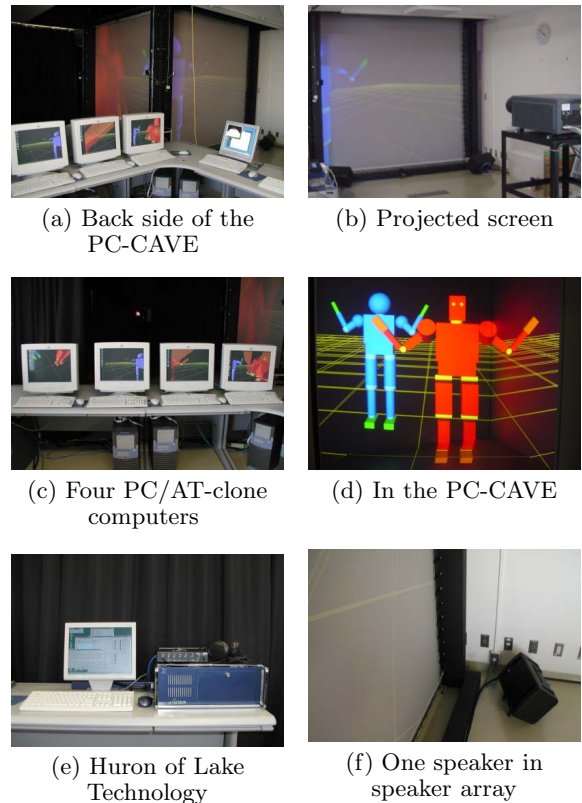


Figure 2: Immersion type display part

netic sensor. The processed images are projected onto 4 screens simultaneously so as to be observed as the 3D image from the human subject.

#### 3.2 Display of auditory information

The display of auditory information is realized using Huron of Lake Technology. Huron is the virtual reality technology that can control two or more sound sources in real time and can generate the virtual sound space with high reality by eight speakers array. Each speaker is set at one corner of the PC-CAVE structure. The applications of the Huron here are to play the sound from a virtual robot, for example, the utterance made by speech synthesis, the sound of footsteps and the sound with tumbling down. In addition, Huron can create the echo effect of sounds within indoor conditions.

### 4 3D dynamic simulator part

The 3-dimensional dynamic simulator calculates the position and orientation of every part of the virtual robot. As shown in the Figure 3, this dynamic simulator is coded by applying the programming library Vortex of CM-Labs Simulations Inc.. Vortex has functions to process the collision check between the links and the dynamic motion calculations of each link in real time. The calculated position and orientation of all links is transmitted to the immersion type display part using TCP/IP. Owing to the high effectiveness of the processing routine, the time delay for rendering on the immersion type display part is very small. The resultant force of the input torque for controlling the robot, the external force applied from the human subject and the gravity

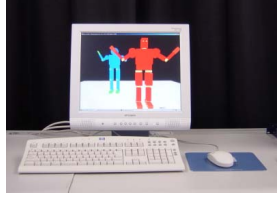


Figure 3: 3D dynamic simulator part

defined in the virtual space decides the motion of the virtual robot. Here, the external force from human subject is sensed using the input device named “WANDA” which is equipped in the PC-CAVE structure, and the other two forces are calculated in the dynamic simulator. The forces added at the virtual robot except virtual gravity is given as follows:

Firstly, PD servo controllers are used to control the joint angles of the virtual robot. The maximum value of the generated torque at each motor for rotating link is limited. The human subject in PC-CAVE can add force to each link of the robot using WANDA, which can sense the position and the attribute of itself and has three on-off buttons and one pointing device. By the on-off button, the human subject can choose a specific link by pushing a button and add the force onto the link. The motion of the WANDA determines the direction and the scale of the force.

## 5 Motion capture part

Considering the affinity of human interactive robot, in this research we designed the humanoid type robot. Moreover, since the detailed specifications of the robot are undecided at the beginning of design, it is generally difficult to evaluate an operation algorithm. We selected the humanoid design for our robot and built the motion capture part for getting the human motion in order to acquire the desired angle for the virtual robot. Some applications of motion capture system have been proposed [10, 11]. In these applications, the proposed systems capture human motion by observing the attached marker movement and control a robot by the captured data.

In our system, the capture data is used to control the virtual robot in the simulator. Here, VICON with six high-speed infrared cameras is used to observe the markers attached on the human body with the sampling period of 120Hz, as shown in the Figure 4. From the precise point of view, it is desired to attach markers on the whole body of the subject, however, since the biped walk of a robot is not easy, in this research, we only focus on the motion of upper body part, especially the movement of both arms. In order to capture the motion of both arms, 16 markers are attached from both shoulders to hands. These markers cover totally the motion up to 10 d.o.f., that is, 3 d.o.f. of each shoulder, 1 d.o.f. of the elbow, and 1 d.o.f. of the wrist, respectively. The measured joint angles are sent to the 3-dimensional dynamic simulator part explained in 4 using TCP/IP and used as the target joint angles of virtual robot. By introducing the 8 force plates on the floor, 32ch electromyographs, and 32ch accelerometers, the motion capture part will be extended so as to measure the torques of human joints [12]. This may makes it possible for the dynamic control of the virtual robot.

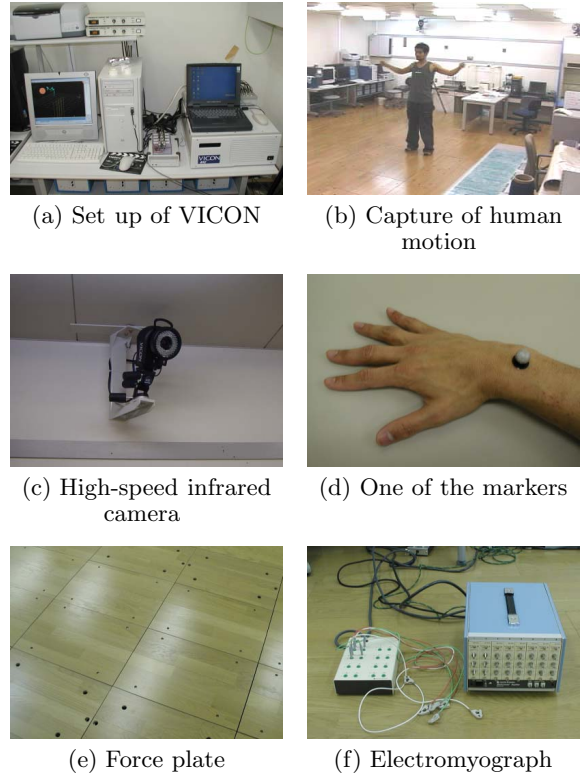


Figure 4: Motion capture part

## 6 Experimental results and Discussions

The experiments using the proposed robot simulator have been performed to show the effectiveness of our research.

### 6.1 Experiments

Figure 5 shows the results of an experiment using our system. Figure 5 (a) shows the motion of a human subject who was attached with 16 markers, and (b) shows the result of motion capture measured by the VICON. 10 joint angles of the upper half body of the subject are calculated from the measurement values of 16 markers attached on the subject. By using these joint angles as the target of the robot, 3-dimensional dynamic simulator part calculates the robot motion and the immersion type display part shows the movement of the subject. The virtual robot, which is displayed by the PC-based CAVE, is shown in Figure 5 (c). The robot located at the left rear of (c) plays back the same motion as human faithfully regardless of its dynamics, and the robot at the forward right basically follows the human motion by PD torque control using 3-dimensional dynamic simulator part with human motion capture data as its target angles. These robots are projected on CAVE through parallel PC-based graphic processing. As a result, the human subject standing in CAVE can feel the life-size of the robot.

The subject can give external force to each part of the robot such as its hand, elbow, shoulder, and head using the wand in PC-CAVE. When external force is given, the movement of the PD controlled virtual robot will be disturbed from the target motion.

Figure 6 shows an example where the subject gave



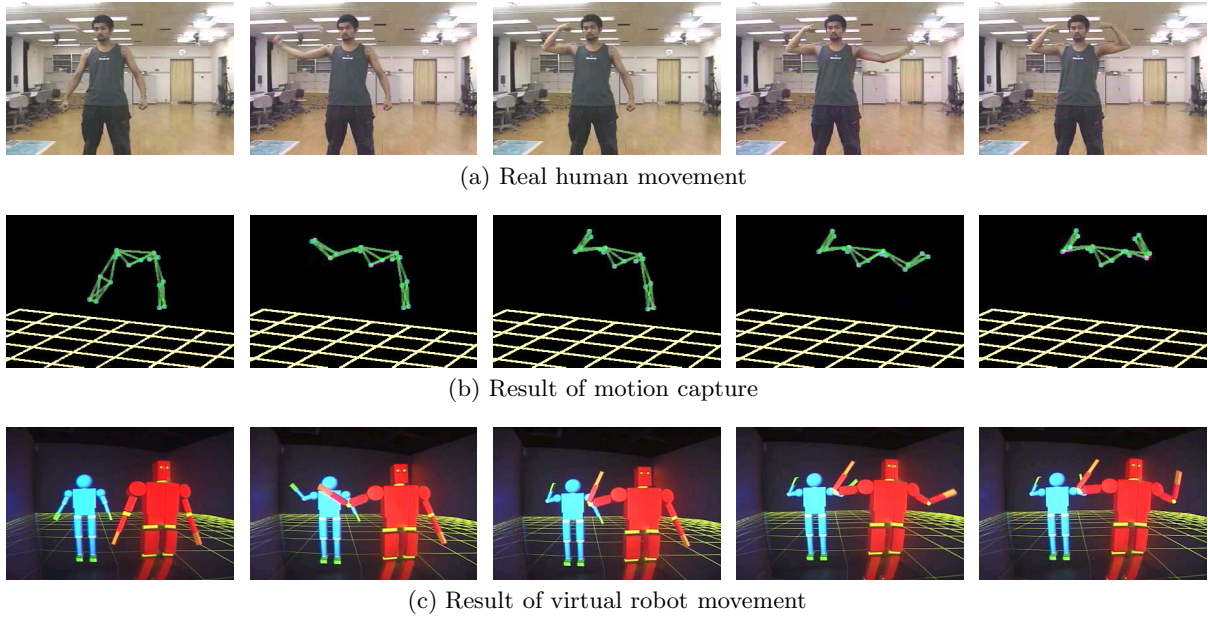


Figure 5: Experimental scene

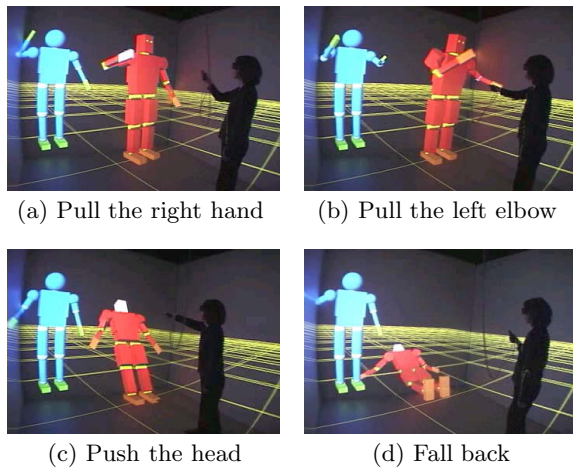


Figure 6: Movement of virtual robot while interacting with human subject

external force by pulling the right hand (a) and the left elbow (b) of the robot. Figure 6 (c) shows the example where the subject gave external force to push the robot's head, and (d) shows the example where the virtual robot falls back by that external force.

Influenced by the activity of these external forces, the postures of the forward right robot differ from the left rear robot, which always follows the motion capture data for comparison. Moreover, when the robot falls back to the ground, the crash sound can be heard from the exact position where it is crashed.

## 6.2 Application to design change of a robot

Since the robot simulator is creating the virtual robot by projection of a projector, it can investigate easily what kind of impression is given to a subject by changing a robot's design of form, color, size, and so on. We cre-

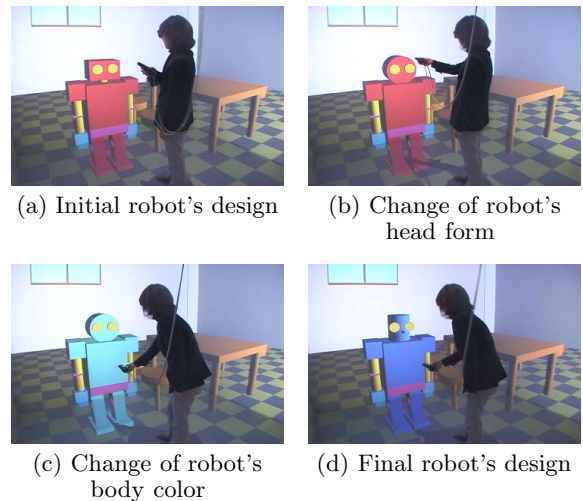


Figure 7: Change of robot's design

ated the application that can change these designs easily. Specifically, in this application, if the human subject touches the robot's head and/or body using the wand, which position and on-off button can be detected, the robot's form and color will be changed accordingly. Figure 7 shows the situation of this experiment. The form of the virtual robot's head and the color of the whole body were changed by the subject. Since the human subject saw the virtual robot with its actual size, the physical feeling of presence was obtained rather than the simulation on the conventional PC display.

## 6.3 Application to sensor simulator

For the human interactive robots, the external sensors such as force sensor as well as visual sensor is also important for the virtual robot to determine its advanced

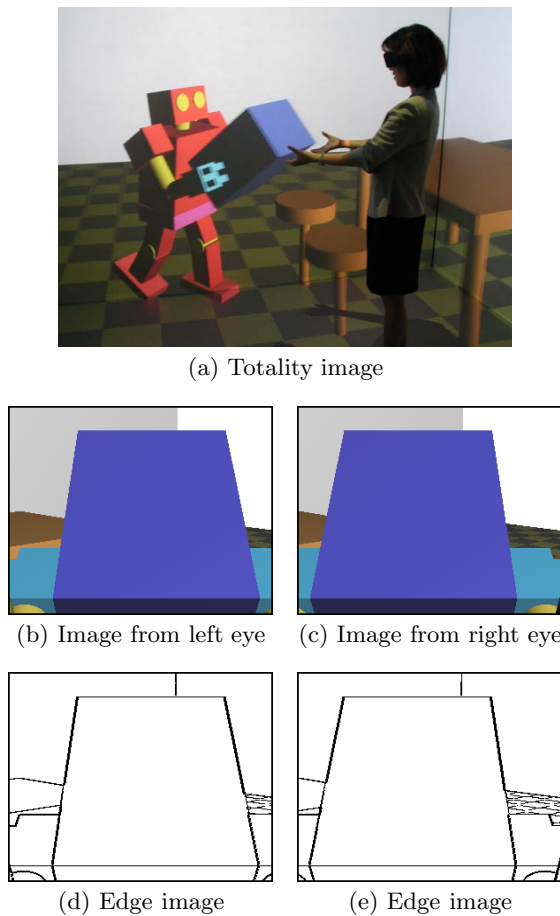


Figure 8: Input image from virtual visual sensor

actions. In our simulator, it is easy for us to add virtual sensors to the virtual robot. It is desired that the processing of virtual sensor information can be integrated to the action of the virtual robot.

Although many kinds of sensors were possible, in the experiment, we constructed the virtual vision sensor and force sensor. For the vision sensor, two virtual cameras were set on the position of the robot's eyes and OpenGL render the input images from the camera. On the other hand, the virtual force sensor is attached on three axis of a joint to measure the interaction force between the links.

We simulated the virtual visual sensor and virtual force sensor. Figure 8 shows the input images by the virtual visual sensor. Figure 8 (a) shows the whole scene, and the images input from the robot's left eye and right eye are (b) and (c), respectively. We understand that the robot is looking at its hand, the box which it is handing and the desk set on the floor. Of course, as shown in (d) and (e), image processing, such as edge detection, can also be performed to the input images. Since human is not modeled in our simulation, there is a problem that the human subject cannot be seen from the virtual robot, it's our future work.

The value of force acquired from the force sensor set in the right elbow is shown in Figure 9. From the top to the bottom, the force of  $x$ -axis,  $y$ -axis, and  $z$ -axis is shown, respectively. In this experiment, since the subject gave external force to the right elbow and upset

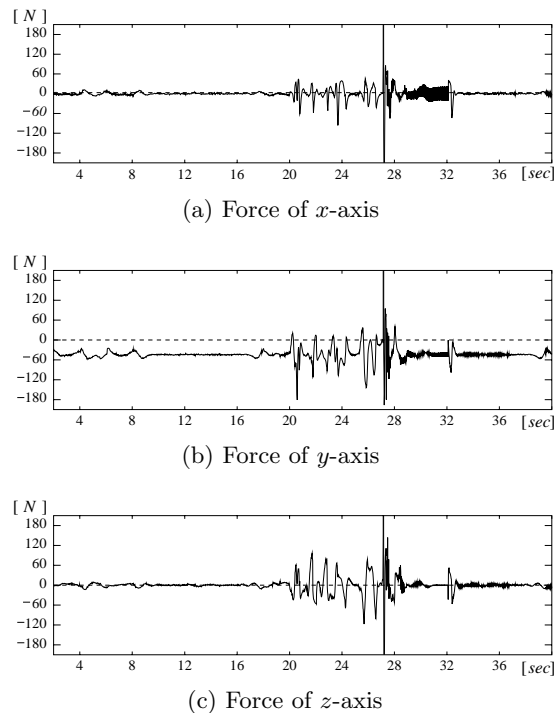


Figure 9: Input data from virtual force sensor

the virtual robot, the value of force is large at the time  $t = 20$  [sec] when the robot received the force at its elbow, and the time  $t = 27$  [sec] when it fell back and collided with the ground.

## 6.4 Discussions

We now discuss about the robot simulator proposed in this paper.

- **The platform of a robot simulator**

In this paper, we proposed the robot simulator in order to develop a robot which interacts with human mechanically in 3-dimensional space. By applying PC-based technology of virtual reality, the visual and auditory information can be given to the human subject in PC-CAVE, and the subject can feel the virtual robot with high reality. Moreover, the subject can give external force to the specific parts of the virtual robot by the wand, and through real time simulation, the resultant robot motion will be displayed. Since the robot created in this research is virtual within the computer, attachment of virtual sensors is easy. We will expect that the virtual robot can actively use its virtual visual and force sensor in performing autonomous movements.

- **The platform of bio-mimetic research**

We controlled the virtual robot using the joint angle obtained by measuring the actual human motions. In order for the robot to mimic the advanced motion like human being, it is necessary and also effective to measure the dynamics of human motions. By now, only the joint angle obtained by motion capture is used in this experiment, however, our system can measure human

body movement much flexibly and precisely in the future by using electromyography (EMG), acceleration sensor and force plate on the floor, From now on, we are going to search for human's advanced movement control mechanism using these systems, and try to apply it in the robot.

- **Future work**

Although this robot simulator gave the visual and auditory information to the subject, it had the problem that a virtual robot could not be touched by now. Therefore, although the subject can give force to robot, he/she cannot receive force from it. Our important future work is toward making such haptic information for the subject. Although research about force display is proposed until now [13, 14], since the magnetic sensor has been used to detect the subject's position and orientation inside PC-CAVE, the present force display will affect the magnetic sensor and cannot be applied directly. In addition, large size of force display will influence the subject's visual information in PC-CAVE. Consequently, we have to develop the force display equipment With not only sufficient power but also small size.

## 7 Conclusions

In this paper, we proposed the 3-dimensional dynamic simulation environment for designing and evaluating the human interactive robots. This environment consists of three parts, the immersion type display part, the 3-dimensional dynamic simulator part, and the motion capture part, and a subject can feel a virtual robot which follows a human motion using the high virtual reality technology. In this experiment, we simulated the motion of the virtual robot, which follows the target motion of human while receiving force from human interactions. Moreover, we developed a function which can change a robot's design easily as an example of application of this research. The vision sensor and the force sensor were developed as a virtual sensor.

At a present stage, the force display between the subject and the virtual robot is not finished, and this development is our future subject. Moreover, we will measure the joint torque generated while man is operating using not only motion capture but also multi channels of electromyograph, 8 force plates, and multi channels of accelerometer. It is our future subject for the virtual robot to mimic the skillful and dynamic movement of human subjects.

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