

## **A CONSTRUCTION METHOD OF VIRTUAL HAPTIC SPACE**

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### **Abstract**

*A method is proposed to construct a virtual haptic space driven by the same environment model of the real world as of the visual space. Human limb motion is measured in real time and the subspace of the total haptic space, which is or will be in contact with the human end effector, is constructed using the haptic space display device. Its end effector is an environment shape approximation device whose shape is specially designed to approximate several shapes by changing its sides of contact. Its position and orientation is controlled by a pantographic mechanism called an active environment display. The shape of the haptic space is approximated by the environment shape approximation device, and inertia, viscosity and stiffness of the haptic space are generated by the use of the mechanical impedance controlled active environment display.*

### **1.Introduction**

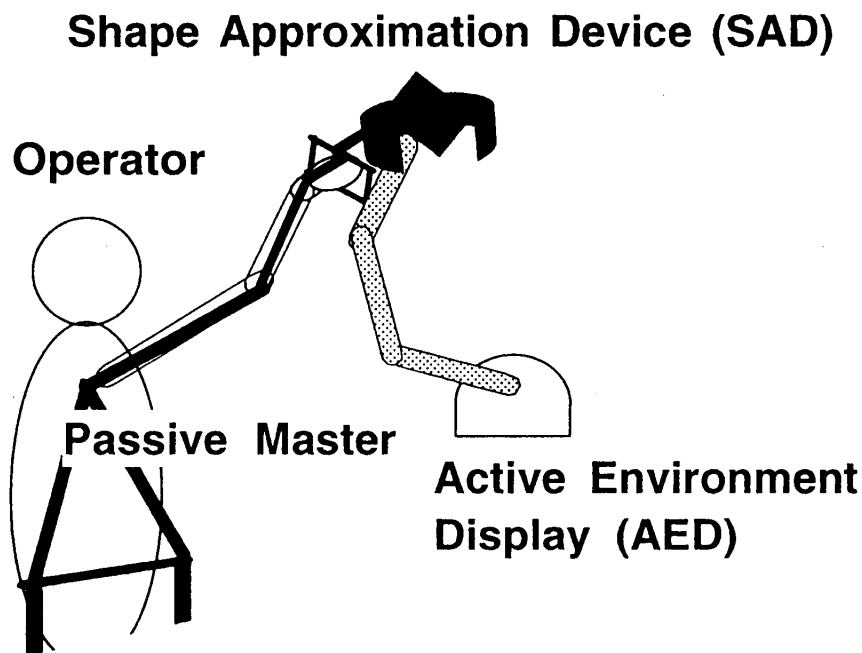
Haptic space plays an important role in virtual representation of the computer synthesized world or the robot transmitted world of the remote environment, such as tele-existence. Tele-existence aims at a natural and efficient remote control of robots by providing the operator with a real time sensation of presence. It is an advanced type of teleoperation system which enables a human operator at the controls to perform remote manipulation tasks dexterously with the feeling that he or she exists in one of the remote anthropomorphic robots in the remote environment, e.g., in a hostile environment such as those of nuclear radiation, high temperature, and deep space. The authors have been working on the research for the improvement of the teleoperation by feeding back rich sensory information which the remote robot has acquired to the operator with a sensation of presence, the concept which was born independently both in Japan and in the United States. It is dubbed tele-existence in Japan and telepresence or virtual reality in the United States [1-18].

In our first reports [3,8], the principle of the tele-existence sensory display was proposed. Its design procedure was explicitly defined. Experimental visual display hardware was built, and the feasibility of the visual display with the sensation of presence was demonstrated by psychophysical experiments using the test hardware. A method was also proposed to develop a mobile tele-existence system, which can be remotely driven with the

auditory and visual sensation of presence. A prototype mobile tele-vehicle system was constructed and the feasibility of the method was evaluated [13]. In order to study the use of the tele-existence system in the artificially constructed environment, the visual tele-existence simulator was designed, a quasi-real-time binocular solid model robot simulator was made, and its feasibility was experimentally evaluated [14].

In the recent papers [15,16], the first prototype tele-existence master slave system for remote manipulation experiments was designed and developed, and a preliminary evaluation experiment of tele-existence was conducted. An experimental tele-existence system in real and/or virtual environment was designed and developed, and by conducting an experiment comparing a tele-existence master slave system with a conventional master slave system, efficacy of the tele-existence master slave system and the superiority of the tele-existence method was demonstrated experimentally [17,18]. Quantitative evaluation of the tele-existence manipulation system was conducted through tracking tasks by using a tele-existence master slave system designed and developed [19].

In this paper, a construction method of virtual haptic space is proposed, a test hardware has been constructed, and the feasibility study has been conducted using the hardware.



*Fig.1 Conceptual Diagram of the Virtual Haptic Space Construction Method.*

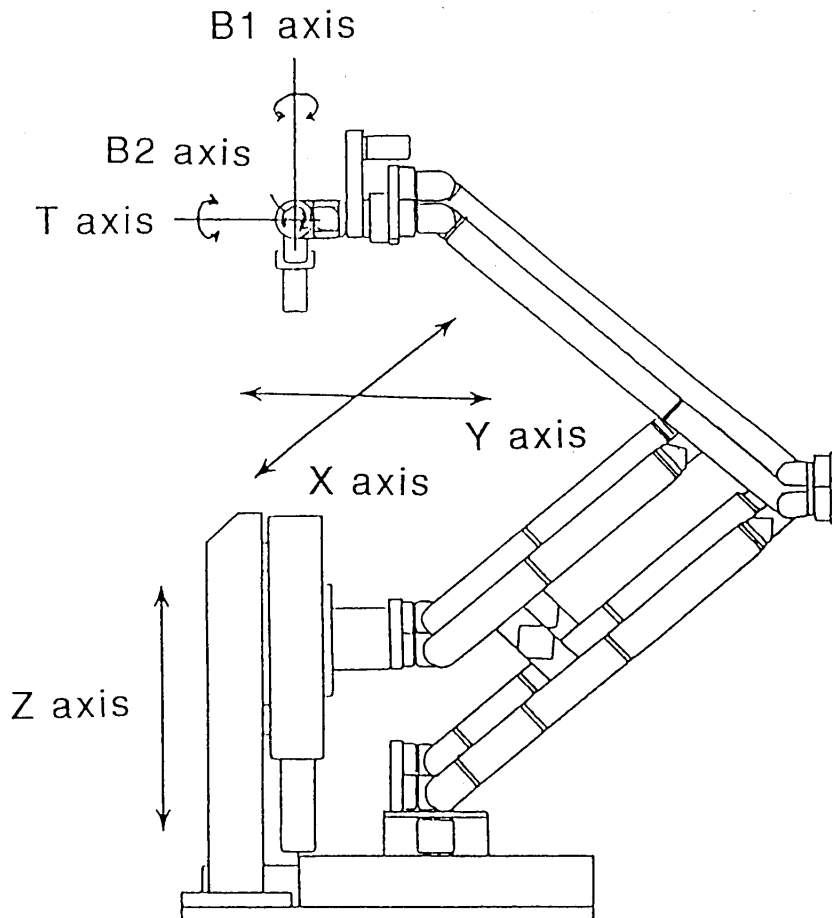
## 2.Virtual Haptic Space

Several efforts have been made for the construction of the virtual haptic space [20, 21]. Most of the developed displays were fundamentally force/torque displays and very few were shape displays. Hirota and Hirose [21] succeeded to construct a shape display of the object with continuous surfaces. However, it could not represent the objects with edges and vertices. In this paper, a method is proposed to represent haptic space with edges, vertices and surfaces with mechanical impedance information, and experimental hardware is constructed to demonstrate the feasibility of the method.

## 2.1 Representation of the Virtual Haptic Space

We restrict our consideration to the case that we could touch the virtual haptic space at one point, i.e. at the finger tip. We also restrict ourselves to the condition that we abandon the representation of the texture of the surface. Then the shape of an object in the virtual haptic space can be represented as a function of three dimensional point of contact  $(x, y, z)$  in the world Cartesian coordinate. One of the attributes of the virtual haptic object is which type of the fundamental shape elements the point of contact belongs to, e.g., surface, edge or vertex together with the normal vector of the surface at the point if it belongs to a surface, or the direction vector of the edge if it belongs to an edge. The virtual object's attribute which we consider other than its shape is its mechanical impedance, i.e., inertia, viscosity and stiffness for three translational directions and three rotational directions.

Figure 1 shows how an object in the real environment is presented in the virtual haptic space. Human upper limb motion is measured by a passive master arm and the tip position and orientation of the human finger is calculated. The measured position is sent to the computer, which calculate the nearest object in the virtual haptic space. The information of the object, i.e., mechanical impedance, tangential surface and/or edge/vertex data is represented by the device which is consisted of a 6 degree of freedom impedance controlled active environment display (AED) and a shape approximation device (SAD).



**Fig.2 Active Environment Display (AED).**

When the finger is in free space, no contact is made with the SAD. However, the SAD continues to display the appropriate shape information at the point nearest to the operator's finger tip. The AED follows is controlled to locate the SAD at the appropriate position based on the measurement of the finger position/posture and the model of the virtual haptic space. When the finger tip contacts the point on the virtual object, the human finger tip contacts the SAD with appropriate mechanical impedance given by the AED. When he/she moves his/her finger, he/she feels the shape of the contact point, whether it is an edge, a vertex or a part of the surface presented using the appropriate part of the SAD. If it is an edge, he/she can find which direction the line is in the virtual haptic space. When it is a surface, surface orientation is represented.

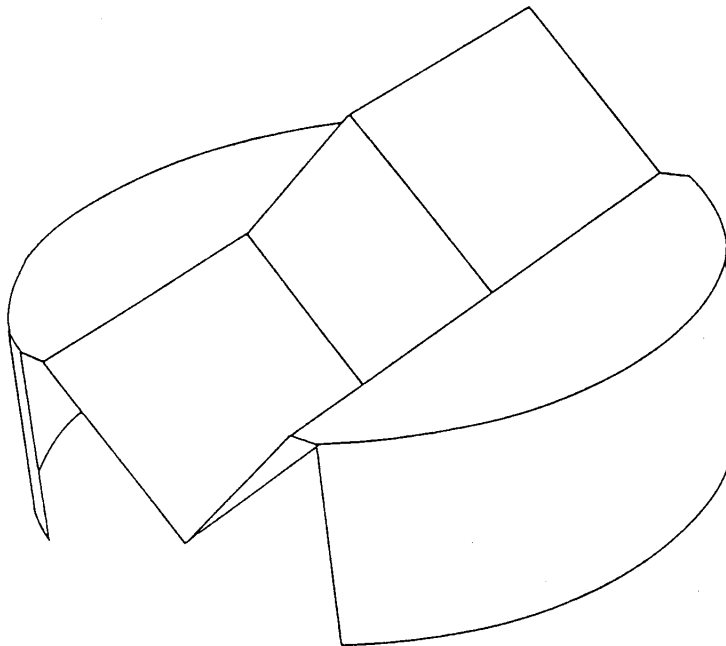
## 2.2 Active Environment Display (AED)

Figure 2 shows the active environment display designed. It has pantographic link mechanism with link ratio of 1:3. The displacements of  $x$ ,  $y$  are magnified 3 times, and the displacement of  $z$  direction is magnified by 4. Auxiliary links are used to make the orientation of the end point of the mechanism independent of the position of the endpoint. This reduces the burden of the calculation for the control.

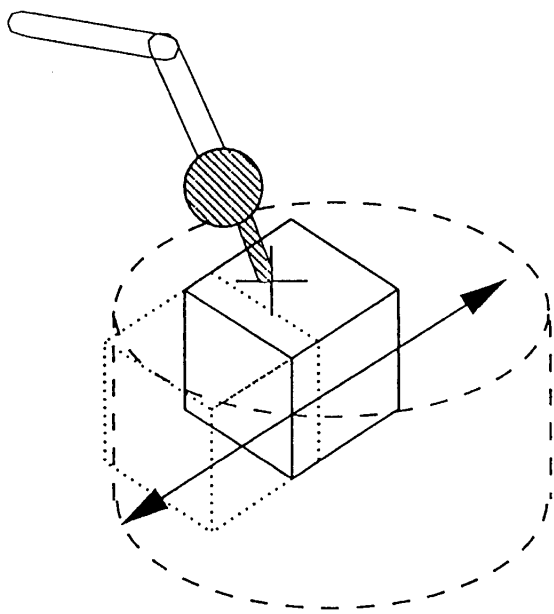
The range of the display is  $\pm 300$  mm for each of the  $x$ ,  $y$ , and  $z$  directions. As for the rotational range,  $\pm 180^\circ$  for yaw,  $\pm 90^\circ$  for roll, and  $+90^\circ$ ;  $-45^\circ$  for pitch.

## 2.3 Shape Approximation Device (SAD)

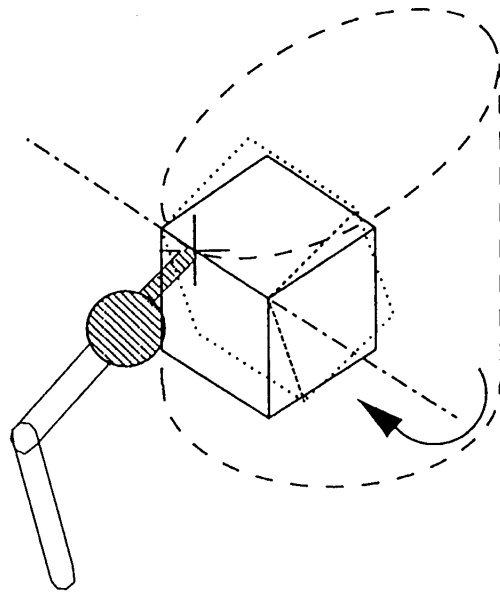
Figure 3 shows the shape approximation device designed, and Fig. 4 and Fig 5 show how surfaces and edges are approximated using the device. Continuous surfaces are approximated by the tangential plane at the representation point. As the contact point moves, the tangential plane follows the point changing its orientation according to the predetermined information.



*Fig.3 Shape Approximation Device (SAD).*

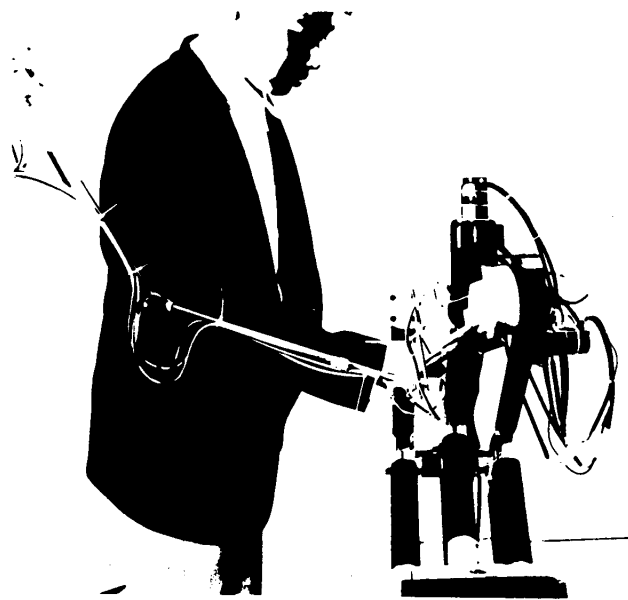


***Fig.4 Surface Representation.***



***Fig.5 Edge Representation.***

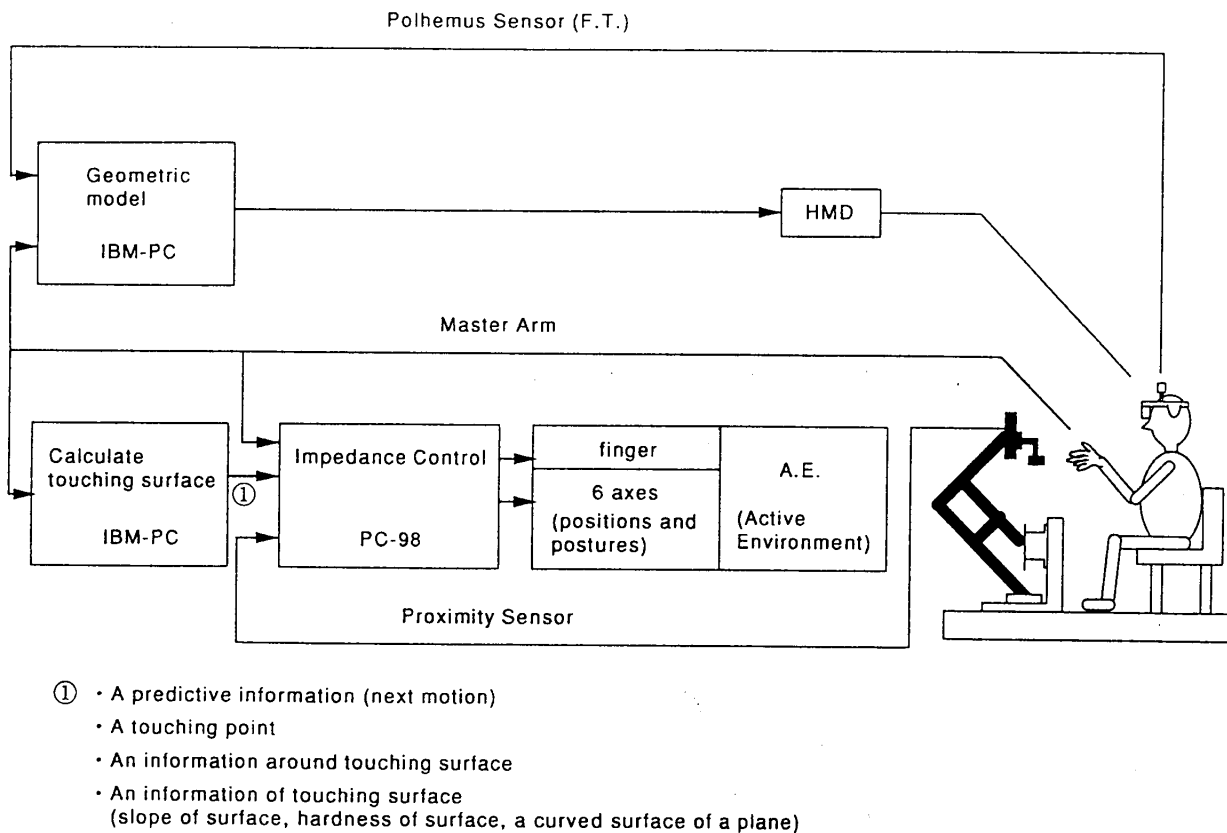
In order to approximate shapes in the environment, the approximation device must represent both convex edges and concave edges. The device has both convex edges and concave edges, and they are used to represent edged surfaces. By controlling the orientation and moving the device to the direction normal to the contact point surface normal, we can arrange any edge at the predetermined position with predetermined orientation. We can also turn the device around the edge presented to construct the predetermined contiguous surfaces.



***Fig.6 General View of the Experimental Hardware System Constructed.***

### 3. Test Hardware

Figure 6 shows the experimental hardware system constructed, and Fig.7 indicates the block diagram of the system. Each object in the virtual space is represented in two ways. One is geometrical representation using polygons as is used in virtual visual space, and the other is represented using sphere, cylinder, cone, generalized cone, cube, parallelepiped, and combination of them. It is represented using the local coordinate fixed to the object in both cases. The position and orientation of the origin of the local coordinate is assigned relative to the world coordinate, and each point on the virtual model is calculated with reference to the world coordinate. Visual information and haptic information are driven by the same world model, and the visual rendering and haptic rendering are conducted in parallel. Nearest part of the virtual object to the finger is estimated by the method similar to the z-buffer method.

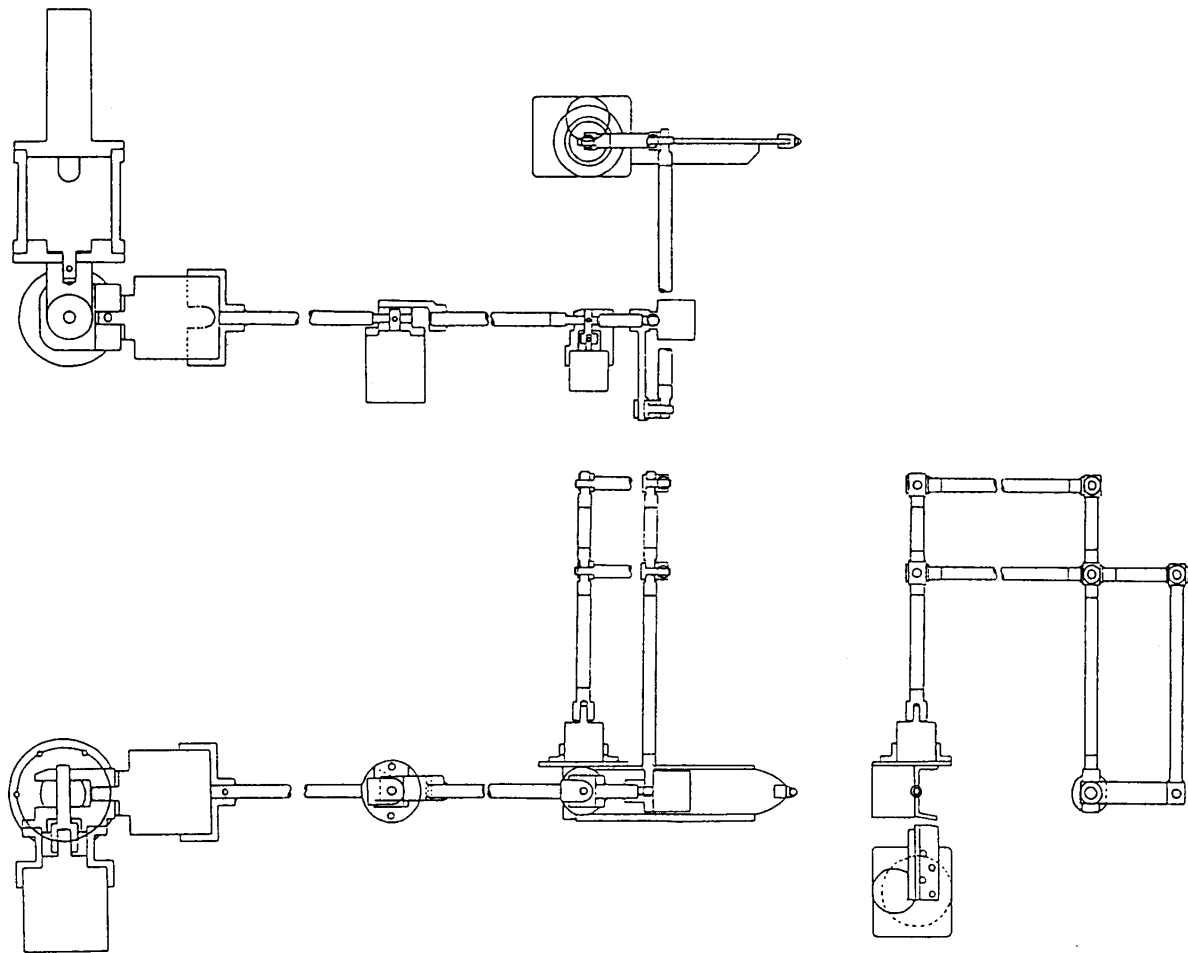


**Fig.7 Block Diagram of Virtual Visual and Haptic Space Presentation System.**

Figure 8 shows the passive master device with seven degrees of freedom to measure the position and orientation of a human user's finger tip position. The human finger is covered by the brace with ball point to ensure the point contact to the SAD. The brace also works to insulate human sensation from the movement of the SAD upon contact.

### 4. Conclusion

A method of constructing virtual haptic space was proposed, and an experimental hardware was made based on the proposed method. It was shown that an object shape with vertices, edges and surfaces could be represented. Concave edges as well as convex edges were successfully represented using the test hardware.



**Fig.8 Passive Master System.**

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