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# CONSTRUCTION EXPERIMENT OF VIRTUAL HAPTIC SPACE BY SHAPE APPROXIMATION DEVICE

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*Abstract:* Experimental results are reported using the proposed method to represent haptic space with edges, vertices and surfaces with mechanical impedance information. The system is intended to provide not only force feedback but also shape information of the contact object during large space interaction with surfaces of various shapes and mechanical impedance. A user wears a light weight passive seven-degree of freedom exoskeleton goniometer that measures the position and orientation of a fingertip. A six-degree of freedom manipulator, which we call "Active Environment Device (AED)," moves to anticipate and if necessary counter the user's action to display contact with virtual surfaces, edges and vertices. The robot manipulator is a pantograph with range of motion of 60x60x60 cm for translation and 360, 180, and 135 degrees for yaw, roll, and pitch, respectively. The wrist of the manipulator carries a device with a complex surface geometry as well as convex and concave edges and flat surfaces. It is thus possible to simulate contact with continuous surfaces and edges by moving the Shape Approximation Device (SAD). Contiguous surfaces are displayed by reorienting the corresponding facet of SAD. A User wears a head mounted display which immerses him/her in the virtual environment. Thus the user can feel exactly what (s)he sees at the position it is observed with the haptic shape just as it is seen. Experiments are conducted to present several shape objects with several kinds of mechanical impedance. It has been shown that an object shape with vertices, edges and surface can be represented. Concave edges as well as convex edges are represented successfully using the test hardware.
*Keywords:* tele-existence, telepresence, teleoperation, haptic display, virtual reality

## 1.INTRODUCTION

Several efforts have been made for the construction of the virtual haptic space. However, most of the developed displays were fundamentally force/torque displays [1,2,3] and very few were shape displays. Hirota and Hirose [4] succeeded to construct a shape display of an object with continuous surfaces. McNeely et al. [5] proposed a shape representation method by using robotic devices, which they called robotic graphics. However, they did not propose the general way of representing objects with edges and vertices. In our first paper [6] and second paper [7], a general 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.

In this paper, experiments, especially coherent visual and haptic presentation experiments with mechanical impedance properties, are reported using the constructed test hardware system.

## 2.VIRTUAL HAPTIC SPACE CONSTRUCTION HARDWARE SYSTEM [6]

### 2.1 Total System

Figure 1 shows the experimental hardware system constructed, and Fig.2 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. They are 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.

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.

Fig.1 General View of the Experimental Hardware.

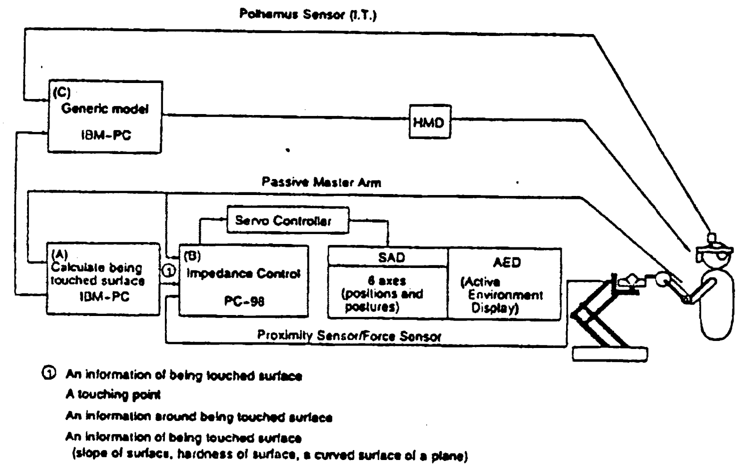



Fig.2 Block Diagram of Virtual Visual/Haptic Space.

2.2 Active Environment Display (AED)

Figure 3 shows the active environment display designed. It has pantograph 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 ±300 mm for each of the x, y, and z directions. As for the rotational range, ±180° for yaw, ±90° for roll, and +90° ; -45° for pitch.

2.3 Shape Approximation Device (SAD)

Figure 4 shows the shape approximation device(SAD) designed. 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.

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.

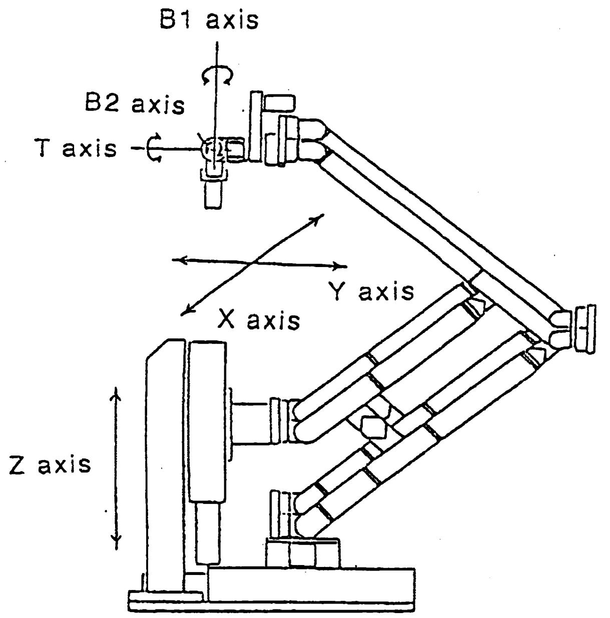



Fig.3 Active Environment Display (AED).

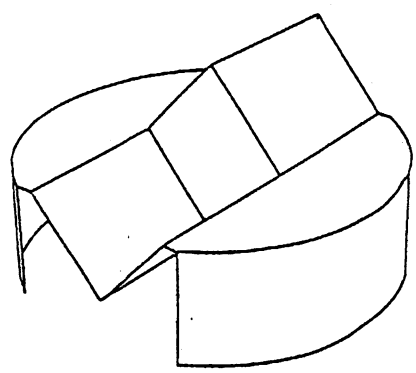


Fig.4 Shape Approximation Device (SAD).

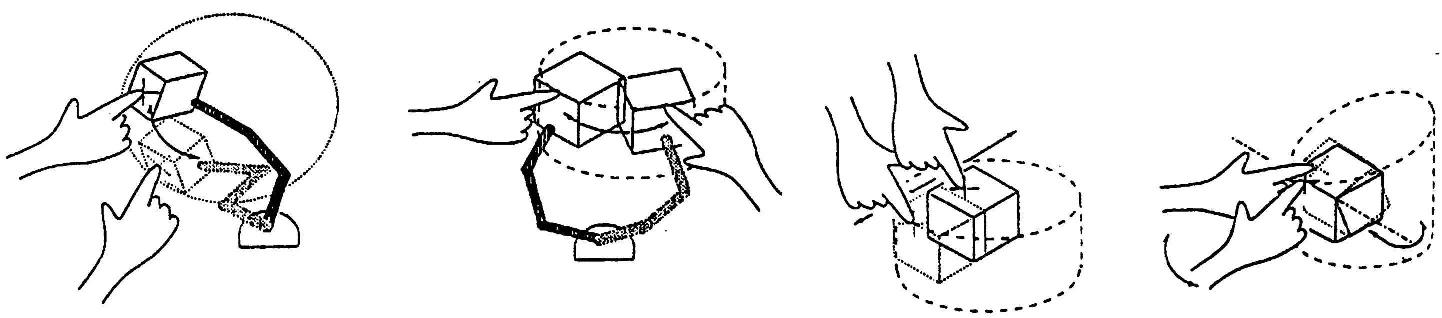
## 2.4 Passive Master

The passive master is a 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.

## 3.EXPERIMENTS

Figure 5 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).

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 (s)he moves his/her finger, (s)he 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, (s)he can find which direction the line is in the virtual haptic space. When it is a surface, surface orientation is represented. Beziere surface representation is used to approximate continuous complex surface as is shown in Fig.6 [7].



(a) A plane/a curved surface

(b) An edge

(c) From a surface to a convex/concave edge

(d) From an edge to a surface

Fig.5 Shape Approximation by SAD.

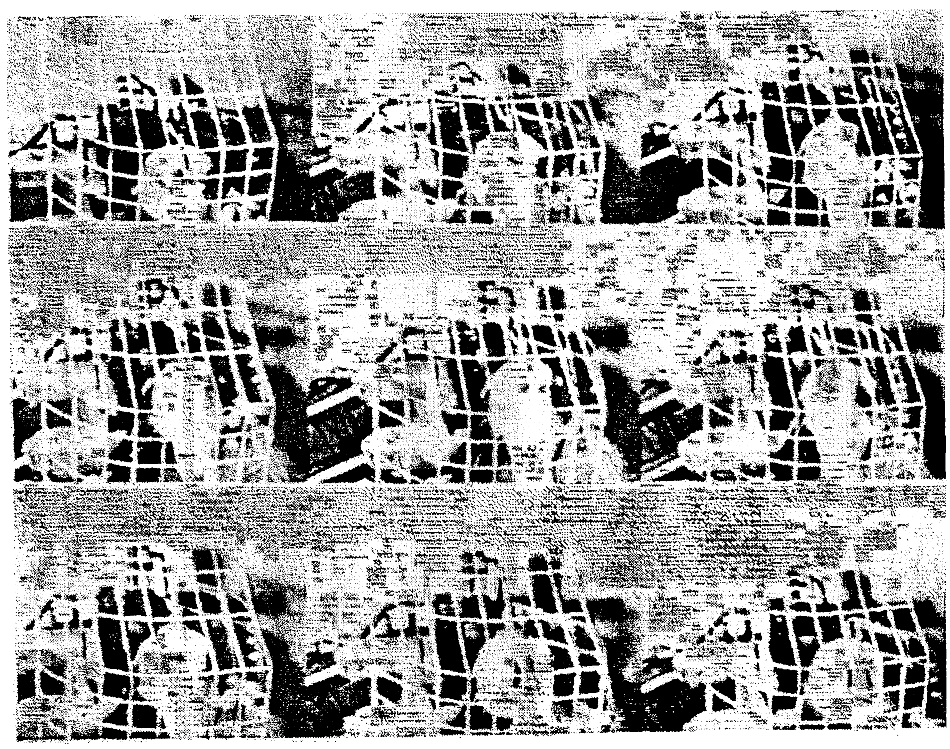


Fig.6 Beziere Representation of Curved Surfaces.

It is possible for an operator not only to see an virtual object but also to feel the shape of the object as (s)he sees it and manipulate the virtual object with assigned mechanical impedance, i.e., with a inertia ($m_0$), viscosity ($b_0$) and stiffness ($k_0$).

$$m_0\ddot{x} + b_0(\dot{x} - \dot{x}_0) + k_0(x - x_0) = F_e$$

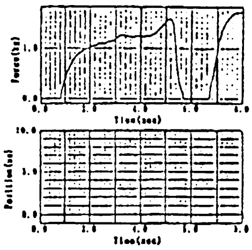
Figure 7 and Fig.8 show some experimental results of impedance realization and friction realization.

$$m\ddot{x} + \mu_1 mg = F$$

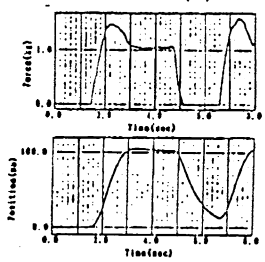
Four types of virtual objects are experimented as are shown in Fig. 9 and Fig.10.

(1) spring
(2) pendulum
(3) ball dribble
(4) valve

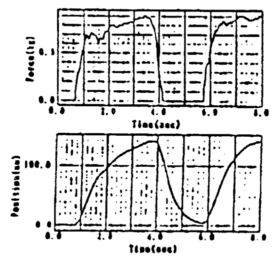
Figure 11 shows force position characteristics of the virtual objects realized by the proposed system.



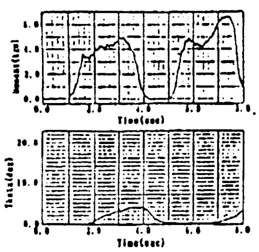
(a) A hard object



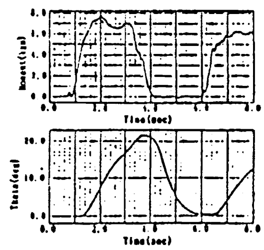
(b) A soft object



(c) A softer object



(d) A block(near the center of the gravity)



(e) A block(near the corner)

Fig.7 Characteristics of the Mechanical Impedance Realized.

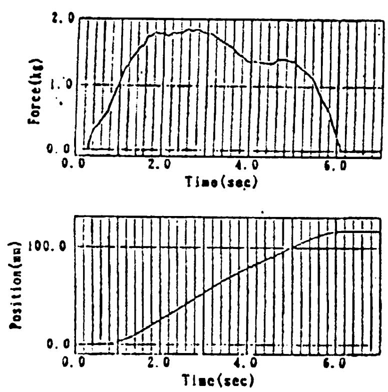
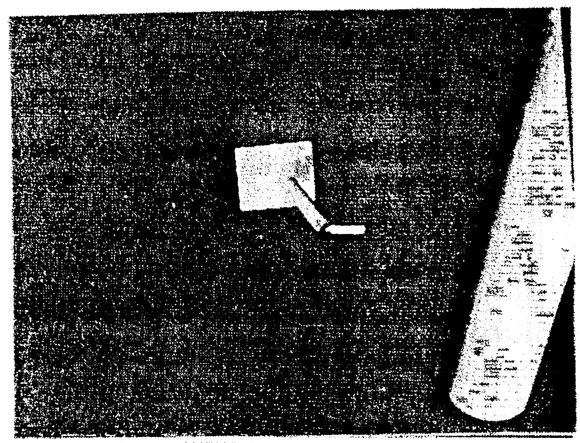
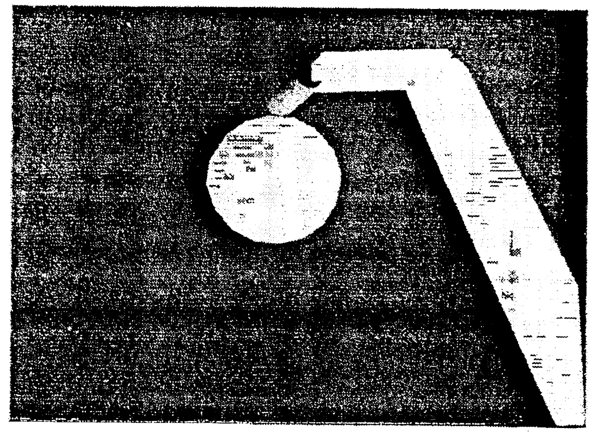


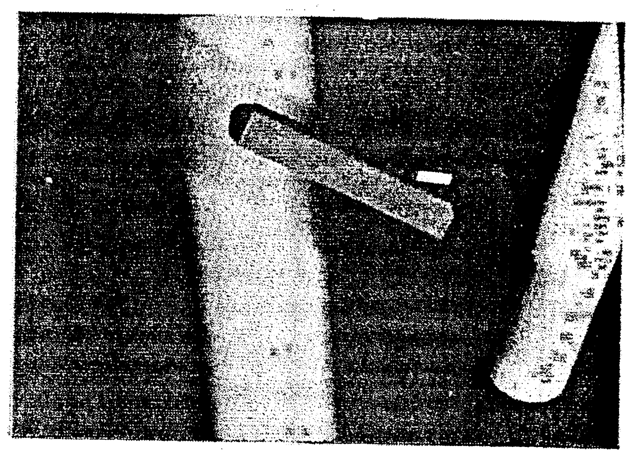

Fig.8 Frictional Surface



Pendulum

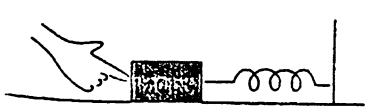


Ball

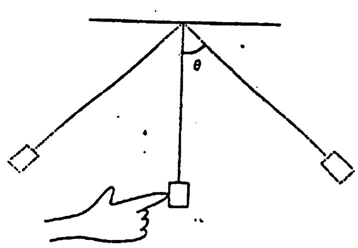


Valve

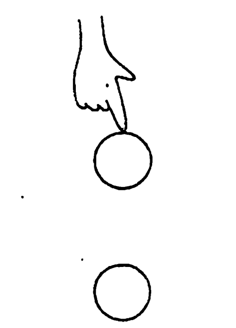
Fig.9 Virtual Objects Viewed by an Operator



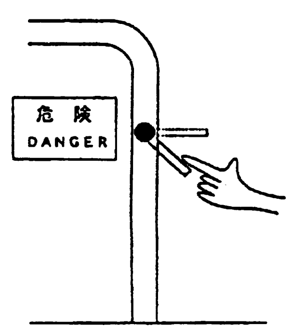
(1) Spring




(2) Pendulum

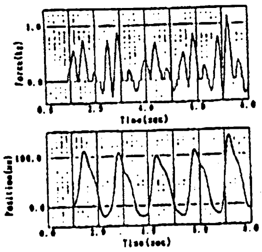


(3) Ball

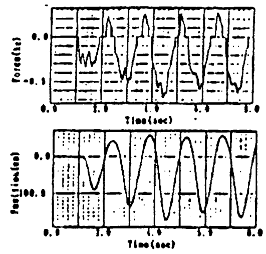



(4) Valve

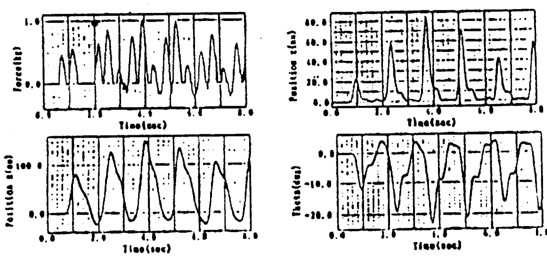
Fig.10 Examples of Virtual Objects..



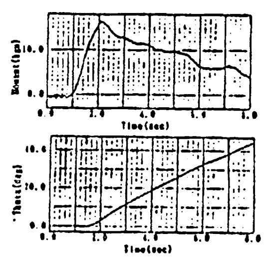
(1) Spring($m_0$=1.0[kg],$b_0$=0.0[N/(m/s)],$k_0$=50.0[N/m])



(3) Ball($m_0$=1.0[kg],$b_0$=0.0[N/(m/s)],$k_0$=50.0[N/m])



(2) Pendulum($m_0$=1.0[kg],$b_0$=0.0[N/(m/s)],$k_0$=50.0[N/m])



(4) Valve($m_0$=1.0[kg],$b_0$=10.0[N/(m/s)],$k_0$=0.0[N/m])

Fig.11 Force Position Characteristics of Virtual Objects Realized.

## 4.CONCLUSION

A display capable of presenting force and shape information of a virtual object was realized by making use of Active Environment (AED) that has pantograph mechanism and controls three positions and three postures (six degrees of freedom) and Shape Approximation Device (SAD) which was installed at the end of AED. The position and orientation of a virtual object was controlled by AED, while the shape of the object was generated by SAD, which had many surfaces and edges. Virtual inertia, viscosity and stiffness were generated by controlling the mechanical impedance of AED. Motion of the virtual object was generated by taking into consideration the friction between the virtual object and the surface of the desk. Thus an operator not only saw three dimensional virtual object but also felt the shape of the object at the exact position where (s)he saw it and could move the object, which responded according to its proper inertia, viscosity and stiffness. The proposed method was installed on a test hardware system, and experiments using the hardware successfully demonstrated the feasibility of the method.

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