A VIRTUAL REALITY SYSTEM USING A VOLUME SCANNING 3D DISPLAY

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ABSTRACT

This paper describes a newly developed virtual reality (VR) system or a data visualization system in which a user can *actually* put his/her hands into the image and can interact with the image in the virtual world) without a helmet or glasses. Therefore, this system can realize a kind of *unencumbering*[1] VR which is very difficult to realize with conventional systems. The system is composed of a volume scanning 3-dimensional (3D) display for creating an autostereoscopic image, an optical relay system for translating the image into another free space, and a multi-dimensional input device for a user to interact with the image. The system has been applied to shape modeling, physical simulation data visualization, and medical data imaging.

Key words:

Volume scanning display; Autostereoscopic image; Optical relay system; Virtual reality; Shape modeling; Visualization; Medical data imaging;

Categories:

3D Visual Display or Virtual Reality

INTRODUCTION

Recently, systems based on the concept of VR has been applied to various fields, such as entertainment, engineering design, tele-robotics, and scientific visualization[1][2][3][4]. Most of such systems consist of a stereoscopic display and a multi-dimensional input/output device. For example, the most famous VR system, RB2 (developed by VPL), which has been widely spread as a standard VR system, consists of a head-mounted display (HMD)[5] and a Data Glove (DG)[6].

These systems are very powerful in making a user feel *reality* of the virtual world. However, it is inconvenient for a user to put a helmet (HMD) or glasses and to wear a glove (DG) whenever he/she interacts with the virtual world. An HMD can realize a kind of full-scale autostereoscopic image, but, there is a time lag between the actual head movement and the update of the image or the scene because the sampling rate of the head position sensor and the calculation speed of data transformation are limited. This irritates the user and sometimes causes a problem like motion sickness. Furthermore, the convergence angle and the focusing control of our eyes are unbalanced in the stereoscopic display since both of them should be used for the depth perception whereas this display can only represent the convergence. This causes a severe eye fatigue, especially when the image is very close to the viewpoint (within 1 m from the viewpoint). Therefore, the current VR system, especially the stereoscopic display, can not be enough for all applications.

The authors' research objective is to realize a VR system which can solve the problems mentioned above and can represent better *reality*. For example, in our virtual world, a user can look at a real-time autostereoscopic image without a helmet or glasses and can also feel that he/she actually touches and manipulates the virtual objects (image). To realize such a system, the display should be *unencumbering*[1] and possible of providing autostereoscopic images. For this purpose, the best way is to show 3D images in real 3D space. There are several works on developing such displays. For example, Traub[7] used varifocal mirror oscillations. Jansson[8] and Yamada[9] developed a volume scanning 3D display. Recently, Benton[10] and Hashimoto[11] tried to develop real-time holography which can display a moving 3D image.

However, an image displayed by current real-time holography is far from being capable of actual use, and the volume scanning displays and varifocal mirror display have the following defects.

(1) All the images are translucent (phantom image).

(2) A user can not reach or touch the virtual object, namely he/she can not put their hands into the space where the image is displayed.

(3) The size of the image is limited by the extent of the moving panel which is very small.

The display presented here basically employs a similar volume scanning method as Jansson's one but has several distinct techniques which can solve these problems.

For the problem (1), the system employs different graphic techniques instead of the usual graphic methods like 'shading' and 'hidden surface elimination' to present the face and the volume in the 3D space.

For (2), an optical relay system is used for translating the 3D image into another free space. If the input device can be operated at the same space as the space where the translated image is displayed, a user can *actually* reach or touch the virtual objects.

For (3), the optical relay system can also be used for magnifying the 3D image, but, it is impossible for a user himself/herself to get into the image. This is the limitation of this display.

Meanwhile, a couple of input devices are being used for detecting the user's hand movement. For applications like 3D drawing or shape modeling, a 3D mouse and a 3D pointer are being used as 3D pointing devices. For applications like data visualization or imaging, a 3D joystick is used for exploring large volume data from the point of time or space.

In the following sections, the subject is mainly focused on the 3D display. The principle and the structure of the volume scanning 3D display, the optical relay system, and applications like shape modeling, simulation data visualization and medical data imaging are described. Topics on input devices and graphic techniques for the display are mentioned with the applications.

VOLUME SCANNING 3D DISPLAY

Figure 1 shows the principle of the volume scanning 3D display. The panel is mounted with illuminants which are arranged lengthwise and breadthwise, and the section image(2D) of each 3D object is displayed in accordance with the position of the panel. If the panel slides back and forth quickly, the section images along the moving direction are joined and a 3D image can be seen (called the afterimage phenomenon). The viewing extent of the 3D image is where the illuminants on the panel can be seen, as shown in Fig.1.

Figure 2 shows the structure of the display. Display data in one plane are read out of the memory and the illuminants are emitted line by line. The luminescence time is determined by the panel moving speed and the number of lines of the illuminants. Therefore, if the panel slides very fast, the luminescence time becomes short and the image becomes dark, whereas the panel moving speed can not be reduced for the afterimage phenomenon to work well. For example, if the panel moves back and forth 30 times per second and there are 100 section planes and 100 lines of illuminants, the luminescence time becomes shorter than 2 microseconds. In order to make the image brighter under the same plane moving speed condition, the display employs the parallelized data readout circuits and also employs red light-emitting diodes (LEDs) for the illuminants since the LEDs are bright and can be switched on and off very quickly. Furthermore, the display has two memory blocks, one for data readout and the other for data writing. Therefore, the processes for creating and displaying data can be asynchronously performed, and the image can be moved smoothly.

There are two types of methods for moving the panel, a rotary type and a translating type , and the display presented here uses a translating type because the luminous density and brightness of the image can be easily controlled in a translating type as compared with a rotary type.

Table 1 shows the display specifications and Fig.3 is an exterior view of the display.

OPTICAL RELAY SYSTEM

A single convex lens or a concave mirror can transform the image into another space, but, the transformed image is distorted since the size of the image depends on the position of the original image(Fig.4). The best way to employ an optical relay system in order to obtain an exact image.

Figure 5 shows the general form of the relay system with two convex lenses L_1 and L_2. In this figure, O is an object or an original image, I_1 is the image created by the single lens L_1, and I_2 is the image created by the relay system. In this case, the right direction is positive, since the light goes from left to right. The relations among the lenses, the object, and the images are

$$\frac{1}{s_1'} - \frac{1}{s_1} = \frac{1}{f_1} \tag{1}$$

$$\frac{1}{s_2'} - \frac{1}{s_2} = \frac{1}{f_2} \tag{2}$$

$$s_2 = s_1' - d \tag{3}$$

$$D = s_2' + d - s_1 \tag{4}$$

$$\tan\theta_1 = -\frac{h_1}{s_1} \tag{5}$$

$$\tan\theta_1' = \tan\theta_2 = -\frac{h_1}{s_1'} \tag{6}$$

$$\tan\theta_2' = -\frac{h_2}{s_2'} = -\frac{s_2 h_1}{s_1' s_2'} \tag{7}$$

where, f_1 and f_2 mean the focal distance of the lenses L_1 and L_2, d is the distance between the two lenses, and D is the distance between O and I_2. s_1, s_1', s_2, and s_2' mean the distances between L_1 and O, L_1 and I_1, I_1 and L_2, and L_2 and I_2. h_1 and h_2 mean the height of the ray of light incident upon L_1 and L_2. θ_1, θ_1', θ_2, and θ_2' are the angles between the optical axis and the rays.

The characteristics of the relay system are

$$(lateral \quad magnification) = \frac{s_1'}{s_1} \times \frac{s_2'}{s_2} = \frac{f_1 f_2}{(f_1 + f_2 - d)s_1 + (f_2 - d)f_1} \tag{8}$$

$$(longitudinal \quad magnification) = \frac{\partial s_2'}{\partial s_1} = \left\{\frac{f_1 f_2}{(f_1 + f_2 - d)s_1 + (f_2 - d)f_1}\right\}^2 \tag{9}$$

$$(angular \quad magnification) = \frac{\theta_2'}{\theta_1} \simeq \frac{tan\theta_2'}{tan\theta_1} = \frac{(f_1 + f_2 - d)s_1 + (f_2 - d)f_1}{f_1 f_2} \tag{10}$$

$$D = \frac{(d - f_1 - f_2)s_1^2 + d(2f_1 - d)s_1 - d^2 f_1}{(f_1 + f_2 - d)s_1 + (f_2 - d)f_1} \tag{11}$$

Therefore, if the two lenses have the same focal distance f ($f_1 = f_2 = f$) and are arranged at a distance of $2f$ ($d = 2f$), a same size inverted real image is always formed at a distance of $4f$ ($D = 4f$) from the object. In this relay system, since all absolute magnifications become unity, the image has no distortion, so long as paraxial rays are assumed.

The same situation happens when two concave mirrors are used instead of two convex lenses. Figure 6 shows the arrangement of the mirrors (M_1, M_2), the original image, and the translated image (O, I). Both mirrors have the same focal distance f and are facing each other with the optical axis in-between at a distance of $2f$. Figure 7 shows the actual arrangement of the two mirrors (f = 250 mm) and the volume scanning 3D display, and Fig.8 shows the original image (right, inverted) and the translated image (left, erected) of a suspension bridge in this system. An exact image is created if the original image is transformed beforehand, like Fig.8.

From Eqs. (8), (9), and (10), the condition for changing the size of the image with no distortion or constant distortion is

$$f_1 + f_2 = d \tag{12}$$

If $f_2 = cf_1$ is substituted for Eq. (12), the magnifications are

$$(lateral \quad magnification) = -c \tag{13}$$

$$(longitudinal \quad magnification) = c^2 \tag{14}$$

Therefore, if the original image is shrunk along the optical axis beforehand, the transformed image will not have any distortion.

APPLICATIONS

Display and Manipulation of Basic Primitives

Figure 9 shows the display of the basic primitives. The system now supports the creation of lines, spheres, cubes, and pillars, and the modification of the location and the size of these primitives. The shape of an object is modeled by editing the basic primitives. Figure 10 shows an example of a 3D drawing, which is created by tracing the movement of the input device. The outer frame shows the display extent.

A 3D mouse (Fig.11) composed of a Polhemus sensor and buttons, and a wireless 3D pointer developed by Digital Stream are used as input devices. For a pointing operation, the wireless 3D pointer is better than the 3D mouse, since its operation space with a high resolution and no distortion can be overlapped with the space where the image is displayed. Table 2 shows some of the specifications of the wireless 3D pointer.

In Fig.9, objects besides the sphere are displayed with a wireframe, but, the display should have the ability to display the surfaces of an object especially when displaying more complicated objects. The displayed image are translucent as pointed out before, and therefore, conventional graphic methods can not be used. Figures 13 and 14 show the graphic methods developed for the display. An object with a complicated shape can be displayed by a mixture of these methods.

Simulation Data Visualization

Figure 15 shows one of the frames (one moment) for simulation data for air flow in a room with an air-conditioner (small box in the right) and a table (box in the center). The small points are tracers for visualizing the air flow. The image data for each moment are sequentially read out of the memory of the computer, and therefore, air flow in 3D space can be visualized.

In the system, the *valuator* on a CRT with a 2D mouse is used for the user to be able to explore the data from the viewpoint of time. A user can interactively play, skip, or change the speed of the image like a video cassette recorder.

Medical Data Imaging

Figure 16 shows the image of a part of the blood vessels in a liver. The outer frame also shows the extent of the display. The original image data were made from data by an ultra-sonic inspection device. The size of the original data was 128 x 128 x 128 and was much larger than the display extent (94 x 30 x 50). In the system, a 3D joystick (Fig.17) is used for the user to be able to explore the large volume of data. The 3D joystick has a cube mounted on 6 touch switches on each surface, and the cube is covered by a box. If a user pushes the box back, forth, up, down, left or right, the corresponding switch turns on, and the computer program changes the image as the display extent is moved.

SUMMARY AND CONCLUSION

A newly developed VR system or a data visualization system composed of a volume scanning 3D display with an optical relay system, and some input devices has been described.

The volume scanning 3D display can create autostereoscopic images without a helmet or glasses, which are very difficult for stereoscopic displays often used in conventional VR systems. The optical relay system translates the image created by the display into another free space. Therefore, a user can actually put his/her hands into the space where the transformed images are displayed, which is also impossible for conventional 3D displays. If an input device takes the movement of the user's hands and the image is changed in accordance with this interaction, the user can have the feeling that he/she is manipulating the virtual world.

The display is made up of a moving panel on which LEDs are mounted. The optical relay system consists of two concave mirrors. A wireless 3D pointer, a 3D mouse, and a 3D joystick are used as input devices.

Although the size of the image is limited, this system can be used for many applications like shape modeling, scientific visualization, and medical data imaging.

The following researches will be required to make the system more powerful.

(1) Enlargement of the display extent

(2) Development of the color display.

An effective method for data expansion and compression should be required for these purposes.

Concerning the input device, a device which can detect the posture or the shape of the hand in the same space where the image is displayed should be developed.

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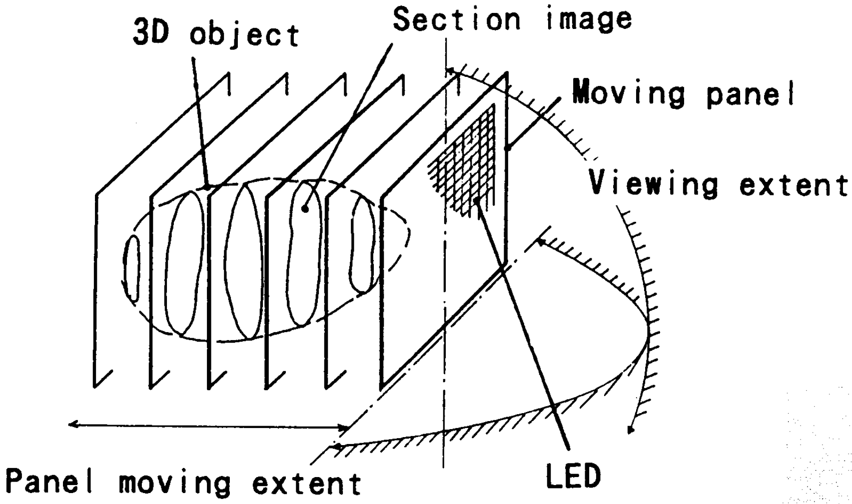

Fig. 1 Principle of display

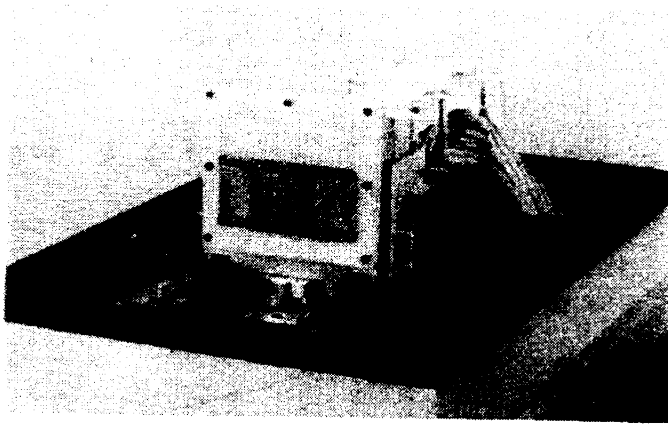

Fig. 3 Exterior view

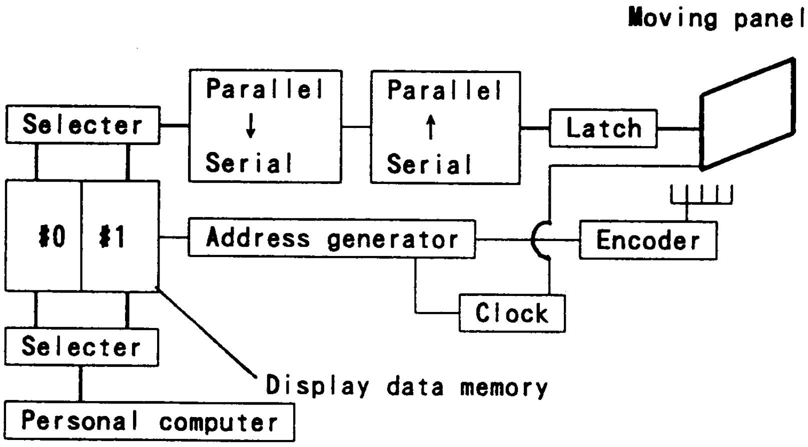

Fig. 2 Structure of display

Table 1

Display extent	94×30×50 [mm]
Picture elements	48×16×50 [dots]
Refreshing(Max)	30 [times/sec]
Color	Orange (610 [nm])
Brightness	50～100 [mcd/m^2]

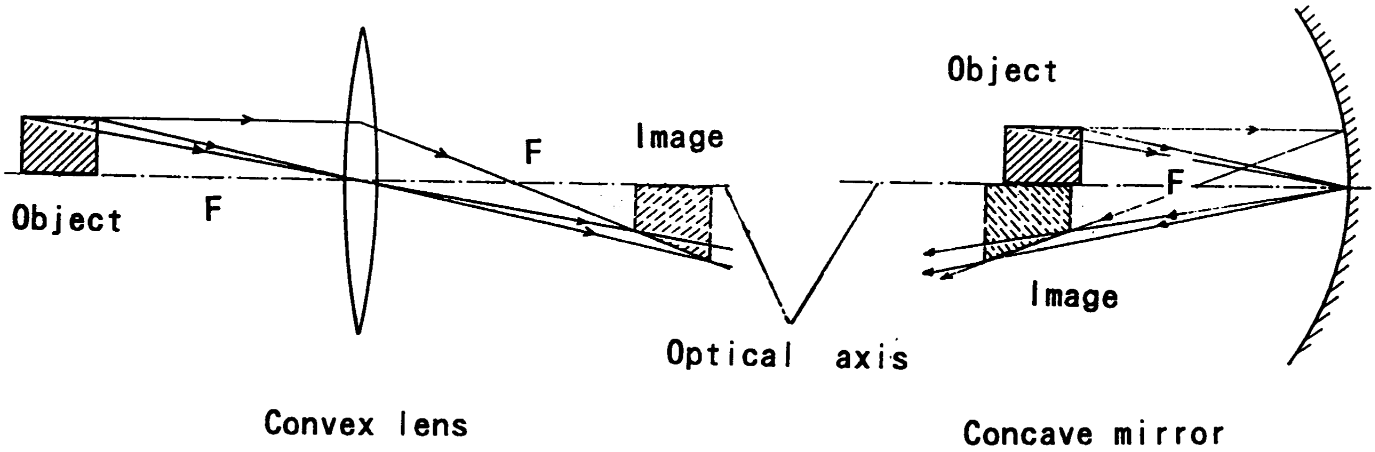

Fig. 4 Image transformation

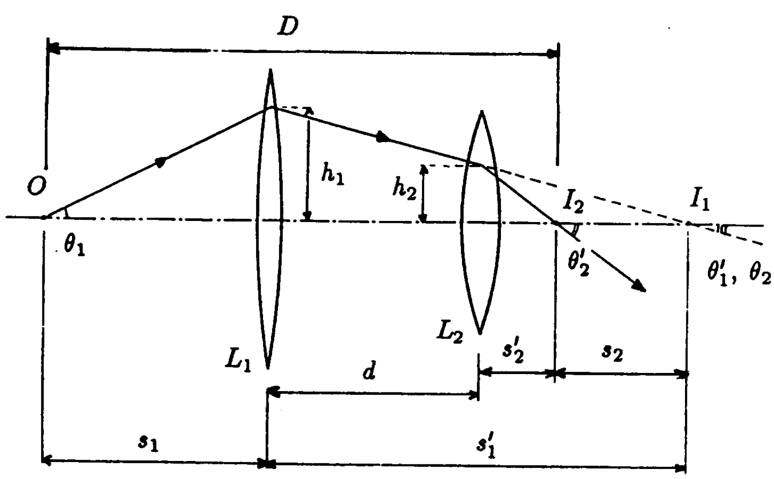

Fig. 5 Relay system

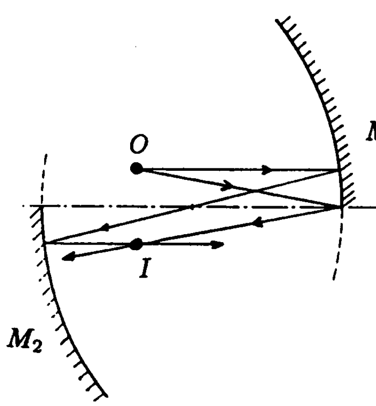

Fig. 6 Mirror arrangement

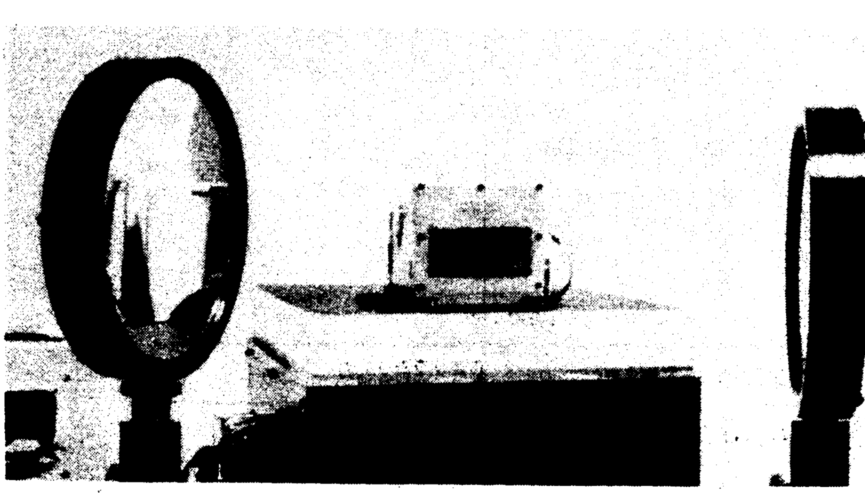

Fig. 7 Mirror arrangement(actual case)

Fig. 8 Original image and translated image

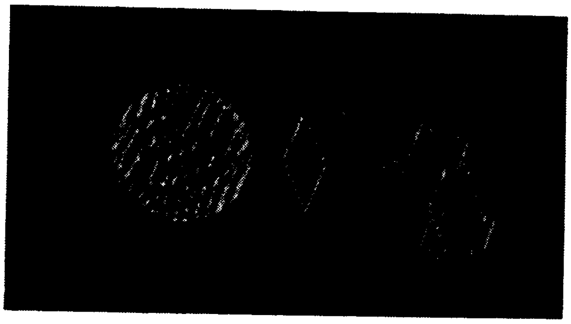

Fig. 9 Basic primitives

Fig. 10 3D drawing

Fig. 11 3D mouse

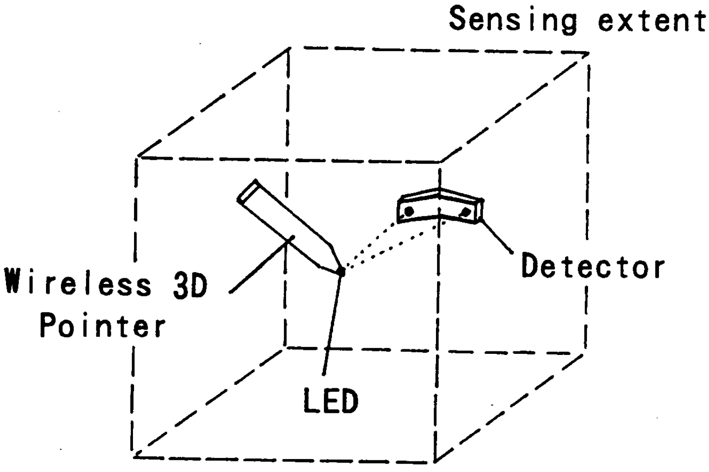

Fig. 12 Wireless 3D pointer

Table 2

Sensing extent	150×150×150 [mm]
Sensing resolution	1.5 [mm/pulse]
Sampling time	10 [ms]

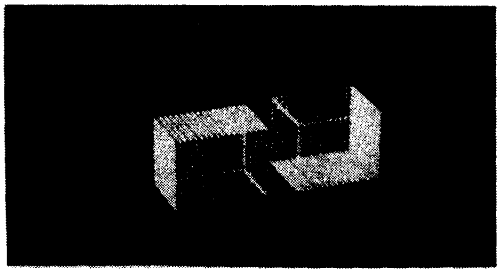

Fig. 13 Side surface drawing

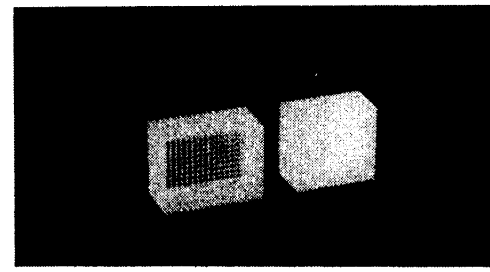

Fig. 14 All surface drawing and volume drawing

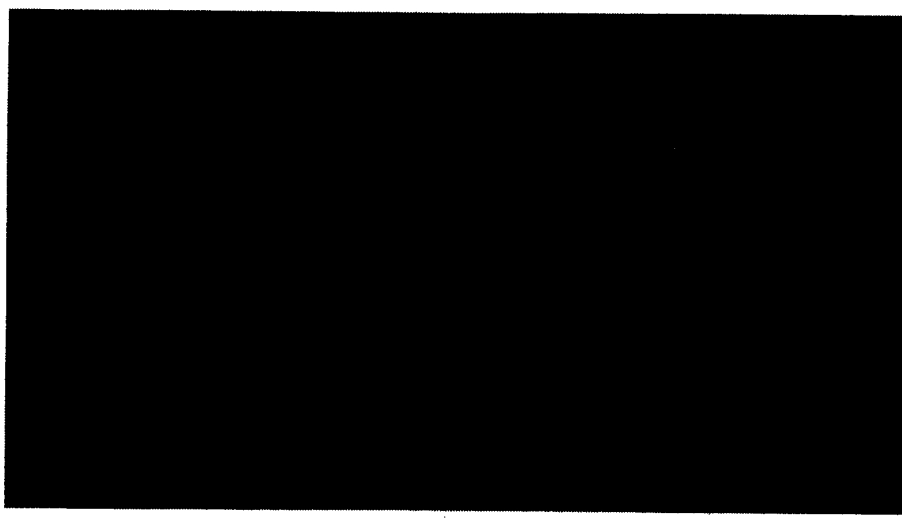

Fig. 15 Air flow simulation

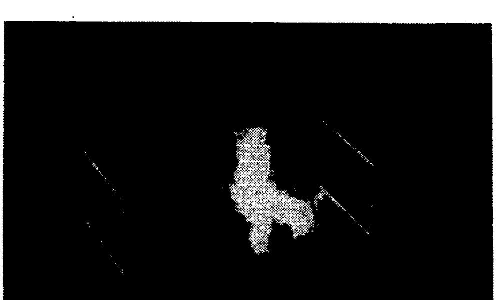

Fig. 16 Medical data imaging

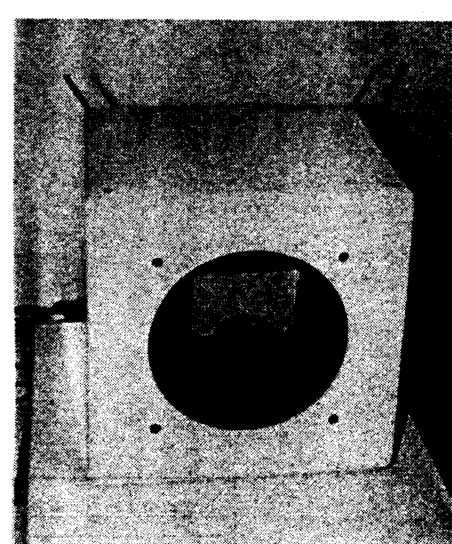

Fig. 17 3D joystick