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Presentation of multiple dimensional data by 6.D.O.F force display

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Provided by a

Abstract

~~This paper~~ describes a ~~new~~ method of represent~~ation~~ing ~~of~~ volume data with haptical sensation. Recently, ~~the~~ volume visualization ~~is often~~ has been used ~~for~~ to analyz~~ing~~e a large ~~number~~ amount of data. However, volume visualized images uses color or intensity of pixel; thus it is hard to display high-dimensional volume data. ~~First we~~ The authors proposed to give force feed back to the volume model in several ways. ~~And~~ then ~~we~~ constructed a test virtual volume model with force feed back ~~by~~ force display system. The performance of the model ~~was~~ is exemplified ~~in~~ volume classification task.

Key words : volume visualization, parallel manipulator, virtual reality, haptic sensation, force display;

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1. INTRODUCTION

Volume visualization is very powerful tool for scientific simulation or experiments which deal a large number of data in the space. For visualization, volume data is mapped to color , intensity or opacity of the pixel. The whole image is generated on CRT screen from a number of such pixel. User can get special feature of space directly. Efficient applications of volume visualization are 1) volume analysis , 2) volume classification , 3) volume synthesis. But , there is one limitation in volume visualization from its own structure. One pixel in the space represents a value of one parameter. Then it is difficult to make volume image of multiple dimensional data. One solution is to use iconification. The arrow icon can present 4 dimensional data (three of direction and one of magnitude) of one point in space. And further more, one parameter can be added by color of arrow. But such complex volume image will be difficult to comprehend.

We propose an idea of integration of visual and haptic representation in this paper. Adding haptic sensation, we expect that user can get extra 6 dimensional input channel . An operator can gets general information from visual channel and he/she can gets local detail information from haptic channel.

We use desk-top force display system as input and output device. The system can provide computer generated stereo scopic virtual space with force feed back. This system is developed for virtual reality application. The advantage of volume visualization by V.R. system is that users can explore volume data interactively.

Our V.R. system consists of 2 subsystem. One is the 6 D.O.F master manipulator as motion input and force output device and other is the Head Mounted Display system as visual output device. Whole system is controlled by a graphic EWS.

A performance of the system is exemplified in volume classification task. As a result, pointing accuracy with force feed back is twice as much as that without force feed back.

2. SYSTEM CONFIGURATION

2.1. Basic Structure of the System

The virtual object manipulation system is composed of two subsystems, a real-time graphic sub system and master manipulator for tactile input and reaction force generation. A graphic EWS and HMD (Head Mounted Display) provide a real time 3D image of virtual space. The overall configuration of the system is shown in **Figure 1.**

Graphic EWS presents two 3D images to an operator., one is left eye image, other is right eye image. The operator can see binocular stereo image. The system measures operator's head by goniometer, The image of virtual space is generated corresponding with the motion data of head. The operator can't see the physical world, only the virtual world that includes 3D pointer. Articulated graphics of 3D pointer is displayed corresponding with the position and orientation of operator's hand as transmitted from the manipulator. This configuration immerses the operator in the computer generated virtual space.

The operator holds a top of the manipulator and feels reaction forces. The force is computed according to model of virtual space.

A personal computer is used as I/O control of the analog-to-digital (A/D) and PWM motor amplifier for the manipulator. The graphics and I/O processor are connected by a serial (RS232C) communication line. The graphics EWS is a SGI IRIS-INDIGO2; The I/O processor is a NEC PC-9801.

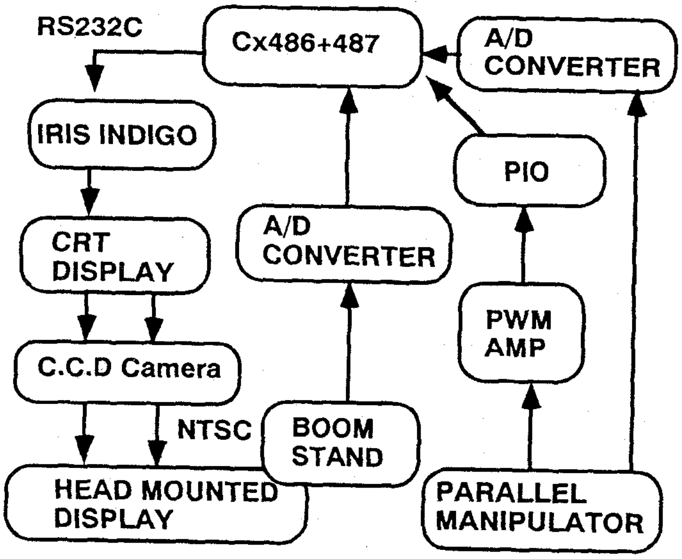

Figure1. Overall configuration of the system

2.2. Image Generator Subsystem

The set up of the image generator subsystem is indicated in **Figure 2.**

HMD: We developed Head Mounted Display system as visual information output device. A stereoscopic 3D-image is displayed on two LCDs mounted in HMD. The human depth sensation uses accommodation of crystal lens in near distance. Then LCD can't be mounted so far from eye for reducing weight and moment. We solve this trade-off by mounting LCD side of head and using plastic 2 mirrors and fresnel lens. One mirror is mounted between EWS Display and CCD camera, other is between LCD and eye. HMD is about 1.5 kgf in weight. LCD size is 4 inch and a field of view is 39.3 degree horizontally, 30.0 degree vertically.

3D-CG: Each 3D-image is generated by GL-library(IRIS INDIGO2). We must exactly match a coordinate of virtual space to the coordinate of space. Then we measured optical specification of CCD camas's lens and fresnel lens's, and computed the optical arrangement of device and the perspective parameter of virtual camera in CG image. An example of the displayed stereo view is shown in **Figure 3**. Its image consists of about 200 polygons, and INDIGO can update view 50 Hz.

Goniometer: The operator's head position and rotation is measured by 6- D.O.F goniometer. The goniometer takes an advantage in an accuracy of data and cost to magnetic 3D sensor. We limited working space in desk top space, and this link system can work well in this area.

3D-Pointer: 3D-Pointer is used as operator's input device in virtual space. Motion of the operator's hand is measured by the internal sensor of the 6 degree of freedom manipulator. The motion data is transmitted from the I/O processor to the INDIGO. The position and orientation of the operator's hand are described in a coordinate system fixed to the virtual space model. 3D-pointer reflects the motion of the operator's head.

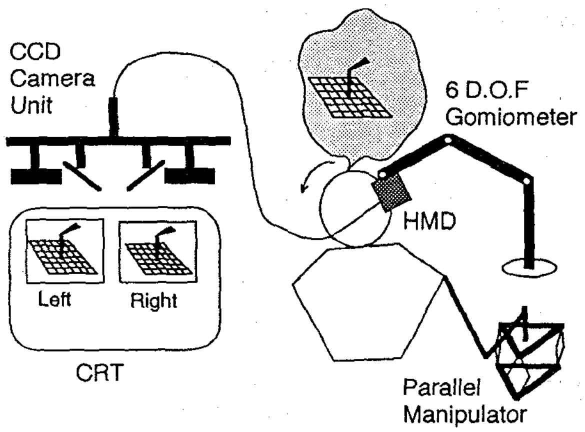

Figure 2 Diagrams of the system

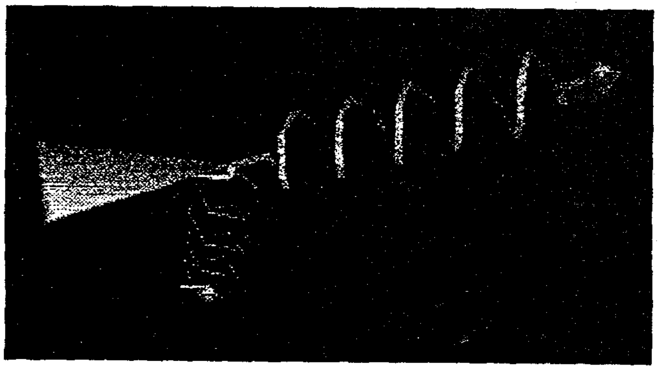

Figure 3 Sample Image of Force Display

2.3. Tactile Input and Reaction Force Generator Subsystem

A 6 degree-of-freedom manipulator was developed as a tactile input device with reaction force generator. The manipulator applies reaction force to the finger tips.

The core element of this subsystem is a 6 degree-of-freedom parallel manipulator. The typical design feature of parallel manipulators is an octahedron, in which a top triangular platform and a base triangular platform is connected by six length-controllable cylinders. This compact hardware has the ability to carry a large payload in any direction. The structure, however, has some practical disadvantages in its small working volume and its lack of backdrivability of the mechanism.

In our system, three sets of pantograph link are employed instead of linear actuators. The mechanism is illustrated in Figure 4. Each pantograph is driven by two DC

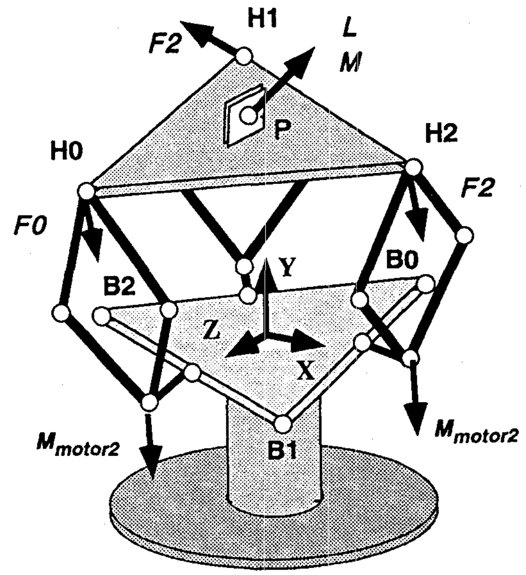

Figure 4. Force & Moment Configuration of improved parallel manipyurator

motors. The top end of pantograph is connected with a vertex of the top platform by a universal joint. This mechanical configuration has the same advantage as an octahedron mechanism has. The pantograph mechanism improves the working volume and backdrivability of the parallel manipulator.

The working space of the center of the top platform is a spherical volume whose diameter is about 30 cm. The maximum payload of the manipulator is 2.1 kgf, which is more than a typical hand.

The operator holds knob which is attached at the center of the top platform. A reaction force is transmitted through the knob.

We generate the reaction force from the following formula:

$$\mathbf{L} + \mathbf{L}_{offset} = \sum_{i=0}^{2} \mathbf{F}_i \qquad (1)$$

$$\mathbf{M} = \sum_{i=0}^{2} \left[(\mathbf{h}_i - \mathbf{p}) \times \mathbf{F}_i \right] \qquad (2)$$

$$\mathbf{F}_i \cdot \left[(\mathbf{b}_k - \mathbf{b}_j) \times (\mathbf{h}_i - \mathbf{h}_j) \right] = \mathbf{M}_{motor} \qquad (3)$$

where

p: a knob of top stage.

p: position vector of top stage

L: force vector of P

M: moment vector at P

$\mathbf{M}_{motor}$: moment by motor mass

$\mathbf{L}_{OFFSET}$: weight of top stage

Fi: force vector at Hi

hi: position vector at Hi

bi: position vector at Bi

The formula (1) indicate the balance of force. The formula (2) indicate the balance of moment. The formula (3) indicate the balance of moment in each pantograph link. The formula (1),(2) and (3) lead to nine dimensional simultaneous equations. The $\mathbf{F}_i$ are obtained by solving the equation by Gaussian method. Generated motor torque are calculated from the Fi in EWS. The force model update frequency of reaction force calculation is about 50 Hz (include serial line communication between EWS and PC)

3. METHOD OF VISUAL AND HAPTIC REPRESENTATION OF VOLUME DATA

When we treat a large number of data within a coordinate volume space, a visual representation form is more helpful for operator than a numeric form. In this chapter we classify major method of volume visualization into sampled data form , then we propose haptical representation method in order to overcome limitation of visual representation.

3.1. Volume Visualization

At first we group sampled or simulated volume data.

A simplest data form is a single scalar type data at one position. (ex. temperature or steam distribution in the atmosphere, electric field) In this case, there is two main methods, one is indirect approach and the other is indirect approach. Cubuerilles and marching-cubes are mainly used as indirect approach. Both method make isosurface which represents the location of same field value in the volume space. The problem of this method is that isosurface can visualize only one threshold at the same time basically. In direct approach, field values are mapped to intensity or opacity (transparency) of pixel directly without making intermediate geometrical object. Making image, ray tracing or projection method is applied in rendering stage.

When we treat data in the field of fluid mechanics, the volume data has vector form. Icons are often used in visualization of vector data. For example, an arrow of each voxel represents vector direction and magnitude of that position. Streamlines are often used, for the same purpose.

More complex voxel volume can be defined. In oceanography, voxel volume of under sea includes velocity of current, water temperature and salinity. One example of visualizing such complex data is that one scalar data is mapped on an isosurface of other scalar data or on arrow icon of vector data. Those visualizing methods can't represent whole data.

3.2. Haptic Presentation of Volume Data

We propose haptic representation method for conbinating with volume visualization. For haptic representing, we added new object in voxel field to show where user is exploring in volume space. We called this object 3D pointer. 3D pointer is directly controlled by operator's movement and reflect any force to operator. An mismatch in 3D pointer and operator will cause confusion in operation.

For single scalar volume, we suggest 3 methods of haptic representation in following equation.

$$\mathbf{F} = -grad\phi \tag{4}$$

$$\mathbf{F}_x = \phi \tag{5}$$

$$\mathbf{F} = \phi \cdot V \tag{6}$$

where

ø is voxel volume, **F** is reaction force.

In the equation (4), force represents gradient of voxel volume. This method is metaphor of electric field. The equation(5) is directly mapping field data to one force or moment. **V** in the equation(6) is velocity of 3D pointer, voxel volume means viscosity coefficient.

Vector type volume is more suitable to haptic representation.

$$\mathbf{F} = \alpha \mathbf{A} \tag{7}$$

$$\mathbf{F} = \mathbf{A} \times \mathbf{V} \tag{8}$$

where

A is vector of voxel volume, **F** is reaction force.

The equation (7) can simulate fluid resistance at any point of volume space. **V** in the equation (8) is velocity of 3D pointer, and **F** can simulate Lorentz force in electromagnetic.

In the case of complex voxel data, we suppose to assign each data to force and moment individually. For example, velocity form data is assigned to force and scalar data to moment.

4. VOLUME SENSORING EXPERIMENT

As a first study in haptic representation of volume data, we studied simple volume classification task with haptic visualization. The subject had a try to search a core of dense distribution. The clues for subjects are visual volume image and haptic sensation.

4.1. purpose

We are asserting that the method of visual and haptic representation could display multiple degree volume data and become useful analyzing tool for a large number of data. Before we construct such tool, we need a special property of haptic sensation (resolving power in each force and separation between any direction forces)

At first, we examined how much the performance with haptic representation progresses better than with visual alone. The tested volume data set that we adapted was complex dense distribution. This data set is single scalar type data set in volume and we could assume many tactile representation method.

The subjects are instructed to count how many high dense parts are there in virtual test space at first, and then point out each core.

4.2. Experimental Set-Up

Virtual test space: The virtual test space is in front of the subject and he/she can observe from any view point from which they likes through HMD system. This virtual space consists of small object and dense distributed volume space. The subject holds this small object (3D-pointer) that can move freely in virtual space. If the 3D-pointer is within dense field, the 3D-pointer is reflected appropriate reaction force from the model. Of course, reaction force is transmitted to operator's hand.

The dense distributed field is displayed as a box walled by red transported material. From the mechanical limitation ,the test space is 100x60x100 mm box area. Max. reflected force is about 1 kgf , max. reflected moment is about 0.15 kgf•m.

Experimental Volume data: The Definition of dense distribution is described geometrically. We assumed a few small objects (from 1 to 5) floating in some medium. Each object have its position and dense parameter.

The no. i's object density øi are defined as follow.

$$\phi_i = \frac{b_i}{1 - \exp[\alpha_i (l - a_i)]} \tag{9}$$

where

l: Distance from center core
bi: Density at core
ai: Factor of reducing
ai: Distance of half-density

(Figure 5. illustrates how density is reduced)

and any point's density in whole space is defined as ,

$$\phi = \sum_i \phi_i \tag{10}$$

At this step, the definition of dense distribution is described geometrically and continuously. We adapted this model instead of really sampled data. Then we have mapped continuous volume data into 3D discrete voxel field value. Actually, each voxel field vale is interpolated from all vertexes within each voxel. A side of one voxel is 5 mm, then number of voxel is 20x12x20 = 4800 counts.

In this experiment , we assume a visually hard volume

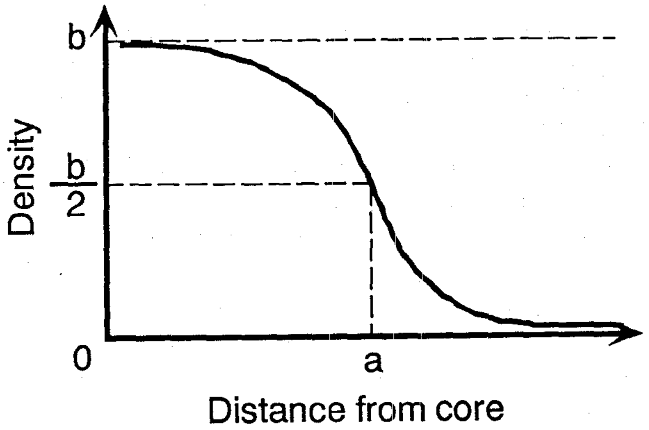

Figure 5. Geometric model of density

classification task. Then the tested volume space is that a few small dense cores are nested in large on. The large one's parameter are bi=0.5, ai=2.0, ai=50(mm). The small one's are bi=0.5, ai=2.0, ai=15(mm).

Volume Visualization: We adapted simplified direct visualizing method. A dense data in each voxel is represented as intensity values of pixel. **Figure 6** is image of tested space. Some small dense cores are nested in the large on , then visual image becomes fuzzy. Mapping volume data to intensity of pixel, the voxel field value are regulated from 0 to 1. Because the value of pixel color intensity ranges from 0 to 1 in 3D graphics library. Further more, we considered non-linear relation in human sensation and input stimulus (Steven's law), then added intentional compensation at this time.

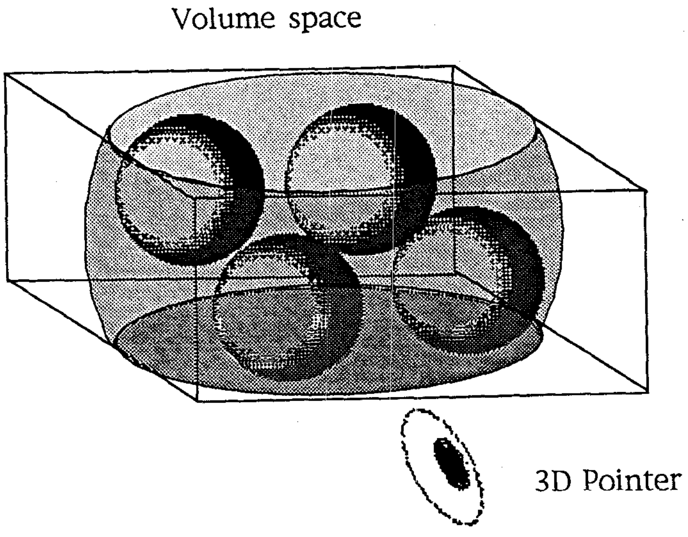

Figure 6 An Image of Dense Distribution

Force generation method: Our volume data is single scalar data set , then we could define many method of force generation. The parameter ϕ is as same as discrete voxel data at volume visualization. Then field data of some point is density ϕ which voxel that point is belonging has.

In this experiment, We use following 2 definitions and 1 convention method and finally visual representation along mode.

(1) Gradient mode (call **G**)

This method is metaphor of potential field. Reaction force **F** is defined in following equation.

$$F=-grad\phi \qquad (11)$$

A difference equation is used instead of differential equation. We hypothesis that a grade of density may became ambiguous, but boundary image will be emphasized in this method.

(2) Moment mode (call **M**)

This method is directly map ϕ to moment.

$$M_y=\phi \qquad (12)$$

$\mathbf{M}_y$ twist operator's hand in the vertical axis. In this method, the other way, we hypothesis that a grade of density is emphasized and a boundary image is ambiguous.

(3) Combination (call **G+M**)

This method is combination of gradient and moment. We expected that this method is most useful than other mode.

(4)Non Force (call **NF**)

This method is only visual representation mode. We thought this mode will be most difficult.

4.3. Experiment

Procedure: For each trial, The subjects was instructed to count how many high dense parts are there in virtual test space and then point out each core. They were told to do the task as fast as they do. Each subjects practiced all trial at once, before measuring trial .

One trial consists of 5 stage. The count of dense core at one stage is random (from 5 to 1), and the whole sum of dense core in a trial are 15.

The computer automatically recorded the position where the subjects pointed out , and after the trial, the average positioning error value was outputted.

Subject: We use three volunteer subject from the staff in our laboratory. All subjects are inexperienced in using our force display system.

Subject	G	M	M+G	NF
A	5.9	7.7	7.0	13.5
B	8.3	6.8	8.0	15.8
C	8.5	9.3	6.7	17.7

(mm)

Figure 7. Performance data of searching task

4.4. Result

Figure 7 shows average of positioning error in distance. All values indicate inaccuracy of pointing task.

From this table , **G**, **M** and **G+M** method are better than **NF** method in common.

4.5. Discussion

An accuracy of any force mode is twice as much as that without force feed back. In this point, hapic visualization is helpful for this task.

There is not so significant difference in **G**,**M**, and **G+M** in this data. But all subjects said that **M** mode is most useful. We analyzed subject's protocol data. In **G** mode, subject can feel boundaries, they, however, misunderstand whether pointer is within an object or not. In **G+M** mode, system reflect force and moment as much as **G**,**M** mode, but, 2 subjects said that moment is less than **M** mode.

These protocol data has important meaning. In fact , sense of moment may be masked by a sense of force. A same phenomenon is reported in a visual sensation or an auditory sensation. Our study's final purpose is visual and haptical representation of high degree volume data, and we must decide interaction of hepatic sense.

5. CONCLUSION& FUTURE WORK

This paper has shown a extension of volume visualization by force display. We proposed several methods of translation field value to force parameter .

Then we examined simple classification tusk. From the result of tusk, we confirmed improvement of pointing accuracy.

Future direction of this studies are:

(1) We observed that human haptical sensation has interactive error as if optical illusion. We think to assign complex volume data to force or moment parameter individually. We must measure this interaction.

(2) The volume model in this examination conceits of only one kind of data. We must examine classification tusk in higher dimensional data in any way.

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