3-dimensional Painting System with Tactile Sensation

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Abstract

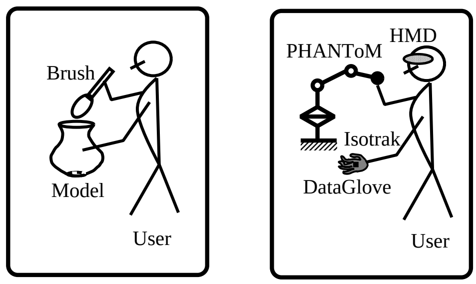
In recent years, many paint tools have been begun to be sold as computer graphics becomes popular. But we have to use it in the way completely different from the painting method in real space . For beginners and painters who are experience in painting real objects,it is not easy to use it. So we propose a paint tool with function that permits us 3 dimensional input operation and returns haptic feedback. And it allows us to move the object by left hand to know the depth to the object. Thereby we think that we can do more realistic working and make express rich.
Key words: 3-D,paint,haptic feedback

1. Introduction

In recent years, much research is conducted to apply a virtual reality technology to the various fields such as a medical care and the education. The use of a virtual reality is to realize the events in a virtual environment that are difficult in a real space. Another use is to improve the operability of the current computer applications. A paint tool is included in them. The 3-D Computer Graphics becomes available in various fields such as movies or CM-s and many 3-D paint tools became put on the market. Those tools have many functions, and the construction of models with high reality is made possible. But the purpose is making CG, and the process is not regarded as important. Therefore, most products use a 2-dimensional input device such as a mouse. The person familiar with such a tool will successfully generate the model intended with the 2-dimensional input device. A beginner or the person who has colored models in a real space cannot realize the intuitive operation with such a tool. It is desirable for them to be able to perform the similar operation in a virtual environment to that in a real space. So the paint tool which exploits the PHANToM as an input unit realized a 3-dimensional input and the sense of a haptic feedback. A paint operation to a phantom object touching it is realized with the instrument, and it is not exaggeration to say that it is the real application of virtual reality. Even if a 3-dimensional input and the haptic sensation were adopted to applications developed so far, the improvement of operability is no attained. We propose the painting tool that permits us to use a stereoscopic vision and that makes the cooperation with both hands possible. By holding an object in a left hand and a writing brush on the right hand. it becomes easy to comprehend intuitively the distance between the brush and the object. This makes it possible for us to get the effect of 3-dimensinonal Input device.

2. System Configuration

System configuration is shown in the Figure1 (b). The position information of a PHANToM corresponds to the position of a virtual writing brush. A user wearing an HMD and a data glove can get deep immersion operating a PHANToM.



(a) Virtual Space (b)Real Space

Fig. 1: Conseption of proposing system

2.1 Stereoscopic vision

As the expression of the virtual environment with a display provides no depth feeling, it is difficult to perform the virtual operation. No one can see the virtual environment freely through a display. So the stereoscopic vision system developed in our lab is adopted in the system. A three-dimensional impression is given keeping the object in the center of a field of vision with this stereoscopic vision system Of course, the position and direction of a head are acquired with the magnetic sensor mounted on the HMD. This allows an operator to see any direction in the virtual environment freely.

2.2 Grasp of object

When coloring an graspable object, he/she will do the task holding it with one hand. So the user uses the data glove with a magnetic sensor on the left hand. When a user grasps an object, it moves according to the hand movement. When the hand is opened, it is fixed there. This permits us to color an object and to translate/rotate it in arbitrary direction holding it in hand. As grasping the position of the object becomes easy by holding it with one hand, it seems that lack of depth feeling in case of coloring is made up for.

2.3 Display of the colored model

A texture mapping is used to realize the effect of the painting action. The coloration data is generated as 2-dimensional pictorial image. By mapping the pictorial image on the 3-dimensional model, the pattern corresponding to the image is generated on the surface of the model. A texture mapping can be exploited in the most graphics libraries and graphics tools. Consequently, it has the advantage that the data formed in this system. are usable to other tools.

2.4 Assignment of Texture coordinate

When a 2-dimensionnal image is mapped onto a 3-dimensional model, distortion often happens and it causes a pattern not intended. The research to reduce the occurrence of distortion has been attempted vigorously[1]. When the 2-dimensionnal image formed in this system is mapped on the model, there is the possibility that distortion will occur on the 3-dimensional image. If the 3-dimensional coordinates acquired in the coloration becomes the same coordinates after the texture mapping, distortion does not occur. So the following two transformation matrices are determined in the way shown below.

- the transformation matrix to form a 2-dimensional texture coordinate from the coordinate on the 3-dimensional model in the coloration
- the transformation matrix to form the coordinate on the 3-dimensional model from the texture coordinate in a texture mapping.

These are decided in the following way. First, meshes consisting of triangle in 3-dimensional model face are defined. By using the vertex of each polygon constructing the 3-dimensional model as the vertex of each mesh, the meshes tracing the shape of the model can be defined. In the texture plane, a set of meshes is defined that holds the same number of elements as those of the meshes defined on the 3-dimensional model. Each element of the meshes defined on the texture plane is corresponded to those on the 3-dimensional model. The transformation matrix Ti from the texture plane on the 3-dimensional model coordinate is obtained from the equation (1). Using it, Ti and the inverse matrix Ti^{-1} are calculated.

$$\begin{bmatrix} x_a & y_a & z_a & 1 \\ x_b & y_b & z_b & 1 \\ x_c & y_c & z_c & 1 \\ N_x & N_y & N_z & 1 \end{bmatrix} = \begin{bmatrix} u_a & v_a & 0 & 1 \\ u_b & v_b & 0 & 1 \\ u_c & v_c & 0 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix} T_i \quad (1)$$

However, $N = (N_x, N_y, N_z)$ is the normal vector of a polygon. When a 2-dimensional image is mapped on a 3-dimensional model, each coordinate of a 2-dimensional image is converted into a 3 dimensions coordinate for every mesh constituent by transformation matrix Ti. Then a 2-dimensional image is generated from the acquired 3-dimensional coordinate using the transformation matrix Ti^{-1}. This keeps the original 3-dimensional coordinate even after the mapping. It is thought that there are various ways for making correspondence between the coordinate on a 3-dimensional model and a texture coordinate. The effective reduction of distortion depends on the applied method. As shown in the equation (2), correspondence is made with the method that an image is put around the axis going through the center of the 3-D model. The texture coordinate (u, v) can be calculated from the equation (2), where $0 < u, v < 1$.

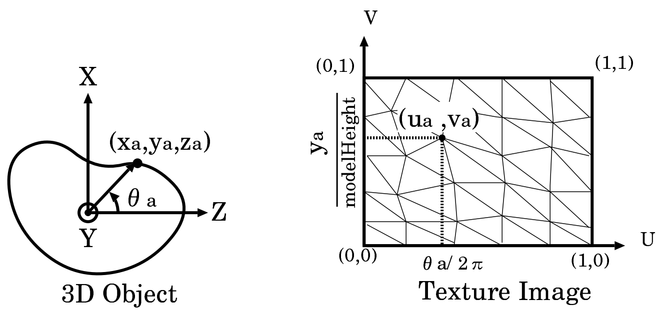


Fig. 2: Assignment of Texture coordinate

$$[u, v] = \left[\frac{\theta_a}{2\pi}, \frac{y_a}{modelHeight}\right] \quad (2)$$

modelHeight :A height of the model(y-axis)

2.5 Procedures of showing the painted model

The followings show the procedures from a coloring one to that showing the painted model.

(a) A 3-dimensional coordinate of the point where a virtual writing brush intersects a virtual object is acquired.

(b) The 3-dimensional coordinate acquired is converted into the 2-dimensional coordinate using the transformation matrix Ti^{-1}.

(c) The coordinate converted from the texture coordinate by applying the transformation matrix Ti is mapped on the 3-dimensional model.

(d) Displaying the colored model.

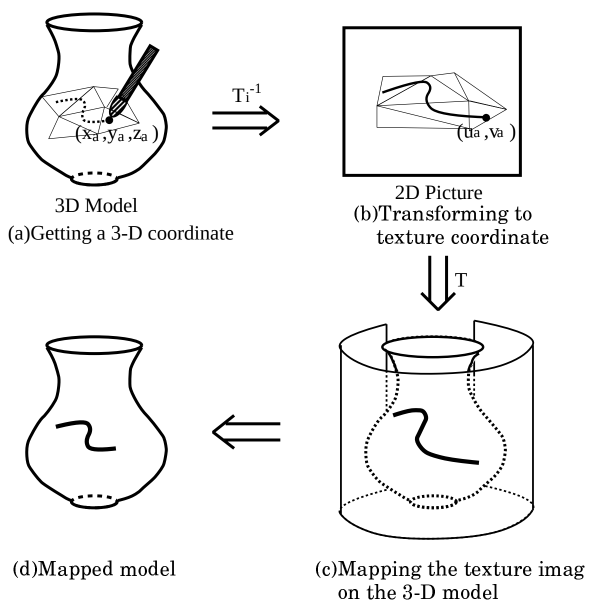


Fig. 3: The procedures from a coloring one to that showing the painted model

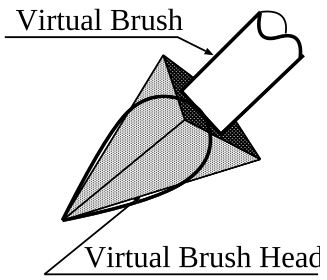


Fig. 4: Virtual writing brush

2.6 The coloration with a writing brush

The coloration with a "writing brush " is supposed in this system. Several models of a writing brush in VR system are suggested[2]. As it is the tool for coloring a model on a 2-dimensional plane it cannot be used as a 3-dimensional paint system. To color a 3-dimensional polygon model, each coloration shape has to be decided every polygon. So as shown in the Figure 4, the writing brush model with a tip shape approximated with a many-sided cone is used in the system. The region in which this writing brush model and the coloration object model interfered is regarded as the coloration region. This makes the position where the writing brush model touches an object model change. As the result, it makes it possible to change a line width without modifying the thickness of a writing brush and more intuitive operation is made possible.

3. Haptic sense

The presentation of haptic sense is necessary in simulating real manual operations in virtual space. A haptic sense has great influence on many handicraft businesses. In the coloration task adopted in this research, both the realization of an intuitive task and the improvement of the feeling of reality are expected through the introduction of a haptic sense.

3.1 Presentation of haptic sense

A haptic model including a writing brash and an objects is necessary to give haptic sense to a writer. According to this model, reaction force is returned to his/her hand. A software called Ghost is used for a haptic model construction. Considering the writing brush, object and paint, there are many parameters necessary to give haptic sense. It is not easy to make a haptic model because there are various influence that causes the deformation to the head of a brush. So a model is construct referring to the haptic model used in the virtual penmanship system[2]. The reaction force F from an object is defined in the following.

$$f = K \cdot dL \quad (3)$$

$$K = g(dL)^2 + K_0 \quad (4)$$

Let K be a spring constant, g be a constant, dL be the distance from the face of an object to the coordinate of the head of a brush and K_0 be the hardness of the object. The Ghost used in this system calculates reaction force based on the spring and damper model. The characteristics of a brush model is adjustable by changing a spring constant, and a damper constant involved in the 3-dimensional model of the brush. So, the equation (4) is given as spring constant of an object. This makes it possible to bring the haptic sense closer to the sense felt when a finger touches the head of a brush. At present, a damper coefficient is not taken into consideration.

4. The experiment

Fig. 5: Painting in the virtual space

The followings are important for this system.

- It will enable he/she to intuition work.
- He/She can draw the picture his own way.

To evaluate them,we made experiments on following. Experimenters operate the brush as trace a design on the object. The design correspond to a picture that user want to paint. We compared the design with results of the experiments to examined the efficiency of the work on earch condition.

We examined the efficiency of working par second from the equation (5) because each experimenter decide to finish the work.

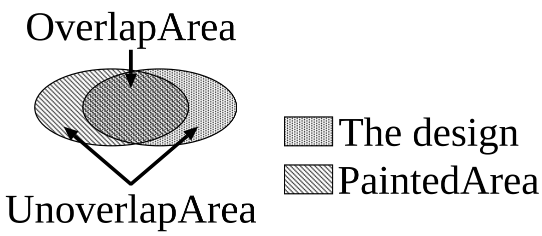


Fig. 6: The overlap area

$$\text{efficiency} = \frac{\text{OverlapArea} - \text{UnoverlapArea}}{\text{DesignArea}} \cdot \frac{1}{\text{Time}} \quad (5)$$

Table 1: Conditions

	Haptic sense	Left hand
Condition 1	With	Without
Condition 2	Without	With
Condition 3	With	With

4.1 Results of working

Examinees could not but become cautious until the head of a brush touched the 3-dimensional model for the lack of depth feeling in the task on the condition 1. Condition 2 is similar to the environment where an object is colored with an extra-fine writing brush. In this case, operators do not rely on reaction force. These conditions caused operators to feel no haptic sense and the writing brush to go through an object when the brush is pushed against the object. Grasping a 3- dimensional model with a left hand is effective to make up for the lack of depth feeling but it is difficult to grasp the exact size of the model as depth feeling is insufficient comparing with the one sensed in real space. After all, painting operation is found to be difficult without any tactile sensation. On the condition 3, a various kind of skill typical to calligraphy become barely possible and a more expressive painting has been attained.

5. The example used

As one of the applications of this system, the conservation of design technologies is supposed. So far the mechanization and automation have been realized for pursuing

Fig. 7: The design

Fig. 8: A expample of results in condition2

Fig. 9: A expample of results in condition3

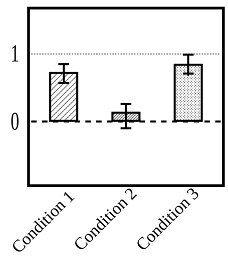


Fig. 10: The efficiency of working

the productive efficiency in the field of much industry. The manufacturing process of handicrafts is also automated, and the mass production of them is done as a result. At the same time the precious techniques of artisans are not successfully stored, they have been lost in recent years. Consequently, the education of successors becomes an important problem. In order to keep these techniques through all eternity, the preservation with intangible cultural asset assignment or the databases consisting of images, photographs and documents are on construction. It is, however, difficult to say that every technical information is preserved in the method shown above. All the information about every engineer should be stored to realize the technical restoration in the future. We think that this system can become a tool to store the techniques of painters. With the system, the movement of a writing brush and the force added to the brush by a painter can be stored as data. Therefore, it can be used effectively for the technical restoration and the education of successors in the future. Further, by exploiting the relationship between action and reaction, the output value of PHANToM can be obtained. This makes it possible to measure the intensity of the force given by an operator during the operation. Consequently, it is expected that much precious information is preserved and exploited thanks to the system from the viewpoint of the design technical conservation.

6. Conclusion

In this paper, an immersed painting system with a haptic sense feedback and a stereoscopic vision was proposed. A painting system allowing a realistic and intuitive coloring is realized using the coloration that reflects the shape of a writing brush. Furthermore as an example of the use of this system, a design technical conservation is examined.

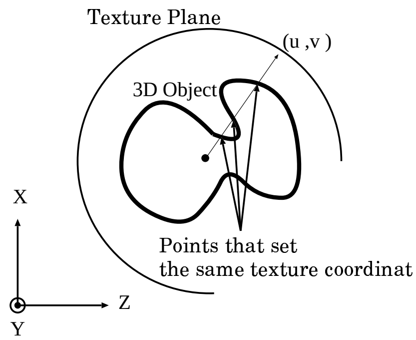


Fig. 11: The point with no correspondence

The technique proposed in the paper isn't suited to treat the coloration onto the top and bottom plane of an object and the shape with unevenness. The v axis of the $u - v$ coordinate system of the texture plane corresponds to the Y axis of the 3-dimensional object coordinate system. When several points with the same value exist in the Y axis direction of the 3-dimensional model, it is impossible to find on the plane made with such points the points which correspond to those on the texture plane. Further, as corresponding points are looking for toward the radius direction from the central axis of the 3-dimensional model, the point with no correspondence occurs as shown in the Figure 11. We have to examine how to define the mesh on the texture plane to solve these problems. Using this tool, we can color or draw a picture on the virtual relic restored from real fragments of relics of prehistoric times with the relic restoration system[4] References.

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