Development of a Geometric Modeling Device with Haptic Rendering

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ABSTRACT

The purpose of the research described in this paper is to develop a geometric modeling device with force feedback and a software system by use of it. Recently, thanks to the advancement of computer hardware, software demanding high processing power has been available at relatively low cost, that has been expanding the ranges of geometric-modeling users for CAD and CG.

In order to enable users without expertise to model geometric objects, we have designed and manufactured a geometric modeling device based on parallel link mechanism and a modeling software system with haptic rendering. The developed device can render haptic information such as resistance force produced by cutting operations as well as input its 3-dimensional position and orientation for the user.

We have adopted point-based geometry to represent objects and made it possible to do set-theoretical operations on complicated objects at such an interactive rate that is not possible for polygon-based geometry.

Keywords: force feedback device, geometric modeling system, point-based geometry

1. INTRODUCTION

Recently, the techniques of the 3-dimensional geometric modeling on the computer are used in many fields, such as the design of industrial products, medical treatments and entertainments. However, their users are not fully satisfied with progress of the geometric modeling technology of generating and deforming the geometry that they imagine in their minds.

Current modeling systems are mainly using the mouse and the keyboard as input devices, but they can not support intuitive operations because they are based on numerical values. Therefore, the development of an interface has been desired that has better operability for geometric modeling.

The purpose of this research is the development of a geometric modeling system in VR (Virtual Reality) environment, and we are proposing a modeling system with a newly developed geometric modeling device with force feedback, and our system renders shapes using point-based geometry.

2. RELATED WORK

A haptic interface device is a device that provides an operator a tactile sense, and the operator can manipulate objects in the 3-dimensional virtual environment and can acquire their feel of touch. Various mechanisms for the haptic interface device have been proposed and they can be classified as follows.

1. Tool assisted type device
2. Wire tension type device
3. Glove type device
4. Contact type device

The tool assisted type device transmits reactive force through a pen, a handle, or spherical gripper. There are a lot of devices adopting robot arm mechanisms in the tool assisted type, and DC motors generate reactive forces. For the input, 6 degree-of-freedom (DOF), 3 DOF of position of x, y, and z and 3 DOF of rotation about x, y, and z axes is very common. For the output, however, various types of devices are proposed with only 3 DOF of position, or full 6 DOF with rotational freedoms.

The wire tension type device attaches threads to the hands and the fingers of the operator, and the tension of these threads generate reactive forces. The SPIDAR which Sato et al. developed is one of the types of haptic interface devices. The SPIDAR attaches a thread to four fingers: the thumb, the forefinger, the middle finger and the third finger, and generates a reactive force to each finger.

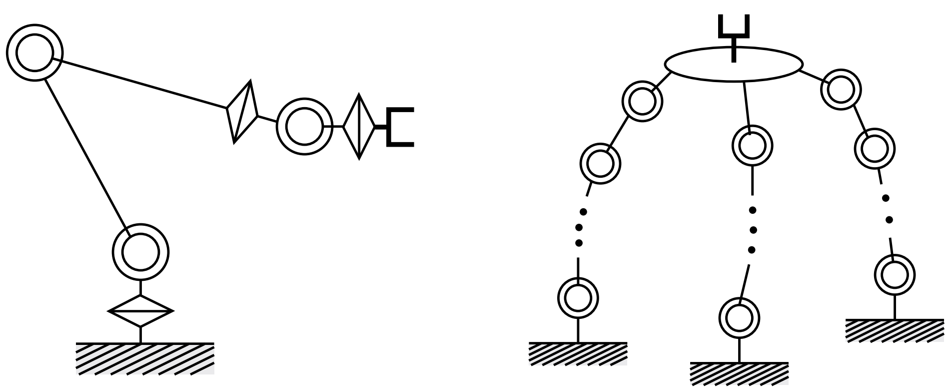
The glove type device is attached on the hand of the user, and it generates a reactive force corresponding to the bending degree of the knuckle joint when the user bends a finger. The glove equips the positional sensor which detects the bending angle of the joint, and the reactive force is generated by pulling the wire connected to the glove with the force corresponding to the bending angle of the finger.

Although these haptic interface devices generate reactive forces when their users grasp or touches some objects with a device indirectly, the contact type device represents a tactile sense by touching objects directly with finger.
FEELEX developed by Iwata et al.[1] is one of the typical devices of the contact type, and is applied to a palpation simulation in the medical field. Although the contact type device can represent a real tactile sense, since the input of the information from its user is difficult to obtain, it is hard to apply to geometric modeling.

At present, haptic interface devices adopting the serial link mechanism such as PHANToM of the SensAble Technologies are widely used. On the other hand, the parallel link mechanism in which a static link and an output link are connected in parallel with two or more links is widely used for 3-dimensional measuring instruments and others, and its features are high speed, high precision, high performance, and high stiffness compared with the serial link mechanism. In this research, we propose a haptic interface device for the geometric modeling using a parallel link mechanism.

2.1 Parallel Link Mechanism

Current robot manipulators adopt two kinds of the link mechanism: serial and parallel. The serial link mechanism is open-loop in which multiple links are connected in series as shown in the Fig.1(a). On the other hand, the parallel link mechanism is closed-loop in which the static link and the output link are connected in parallel with multiple links. The comparison result of their features is shown in Table 1.



(a) Serial link (b) Parallel link

Fig. 1. Mechanism

Generally the serial link mechanism is widely used for manipulators. However, the basement of the actuator must support the total weight of its links and other actuators and its movement performance is limited. Moreover, the deterioration of the precision by accumulation of positional errors is a problem.

On the other hand, the parallel link mechanism can set up all actuators in a fixed part, and can reduce the weight of a moving part. Furthermore, the parallel link mechanism does not have the accumulation of the positional error, and it is highly precise compared with the serial link mechanism. Since the output of each actuator is added, a high performance can be realized.

Feature	Serial link	Parallel link
Actuator	Serial	Parallel
Force	Small	Large
Work range	Wide	Small
Inverse kinematics	Difficult	Easy
Forward kinematics	Easy	Difficult
Error	Accumulated	Averaged

Tab. 1. Comparison of mechanism

Here we discuss the merits and the demerits of the parallel link mechanism applied for the geometric modeling device. The Input of a position of the high precision is necessary in geometric modeling to realize accurate geometric operations. Therefore, the parallel link mechanism is more suitable for geometric modeling device in comparison with the serial link mechanism in which the accumulation of the position error occurs. The geometric modeling device is desired to be a small size which can be used on the desktop. Therefore, the wide work range is not necessarily required. A parallel link mechanism is not problematic applied for a geometric modeling device, although its work range is narrow. Furthermore, the moving parts of the parallel link mechanism are light-weighted. In order to render a real tactile sense, a haptic interface device should be used in a state as close as possible where the user forgets the existence of the device, and high transparency of the mechanism is desired. Therefore, the moving pars of the device must be light-weighted to realize outstanding operation feeling. Also in this aspect, the parallel link mechanism is superior to the serial link mechanism. The parallel link mechanism can use the actuator of the low performance because it is high performance more than the serial link mechanism. Hence, it is possible to decrease the cost of the actuator and the total cost of the device can also be reduced.

As a conclusion, the parallel link mechanism is suitable for the geometric modeling device.

2.2 Point-based Geometry

Although the polygon is generally used as a rendering primitive in CG, a new rendering technique called point-based geometry which uses the point as a rendering primitive has been proposed in recent years. The rendering process of the complex object is performed at high speed because connectivity information with other points is unnecessary for rendering objects described by point-based geometry though the connectivity information of the polygons is necessary for rendering them. In point-based geometry, since one serious problem is how to fill up gaps among the points, various techniques have been proposed.

Grossman and Dally[3] proposed a rendering technique of a set of points called pull-push. At first, from a picture with many holes, the technique generates a low resolution image of the picture. Then the holes of the original picture are filled by referring the low resolution image. Rusinkiewicz and Levoy established a method for rendering a large set of point data obtained with the 3-dimensional measuring instrument by the technique named QSplat[4]. Zwicker et al.[5] proposed a rendering technique which uses surface element (surfel). The surfel is a rendering element defined by its position, normal, information on its color, its radius. In order to render a surfel, a quadrangle or a circle is rendered as a plate (Splat) instead of a point. By using these techniques, the rendering process of the complex object is performed at high speed. However, the problem of editing objects defined based on point-based geometry was not solved. Adams et al.[6] addressed a technique of the boolean operations of the objects defined by surfels. Since the inside-and-outside check of the surfel is achieved at high speed, the boolean operation can be performed interactively.

In this research, the modeling process to deform object defined by surfel is implemented using the technique proposed by Adams et al.

3. SYSTEM OUTLINE

The outline of the geometric modeling system developed in this research is shown in Fig.2. The system consists of a geometric modeling device that can input a three dimensional position and a posture and can output a vectored tactile sense, a control box for device control, a computer and a geometric modeling software system.

The user moves the pointer in the virtual environment freely using a device, and can do modeling and painting. Since the feeling of cutting resistance and contacting the surface can be felt through a device, the user can operate intuitively.

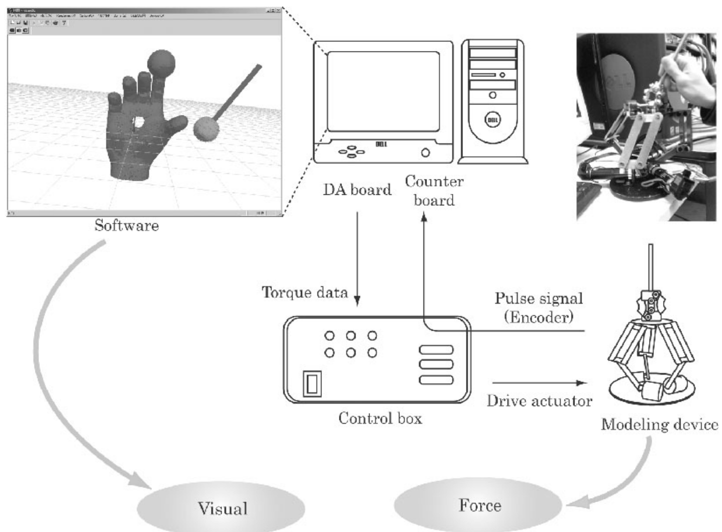


Fig. 2. System outline

4. GEOMETRIC MODELING DEVICE

A geometric modeling device with the delta type parallel link mechanism has been developed in this research.
The device can input the position and can output tactile sense of 3 DOF of the translation. Moreover, the posture input of 2 DOF is enabled using the High Angle Active Link developed by NTN Corp. The physical size of the geometric modeling device is about $216\times216\times320$ [mm^3], and its work space is $140\times140\times100$ [mm^3]. The illustration of the High Angle Active Link is shown in Fig. 2.

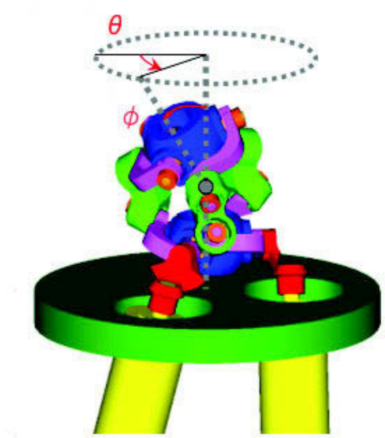
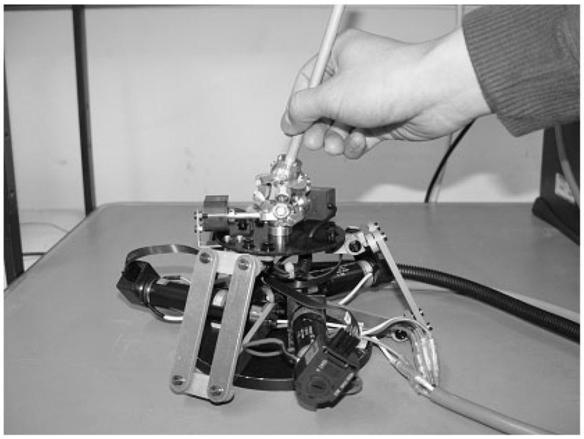
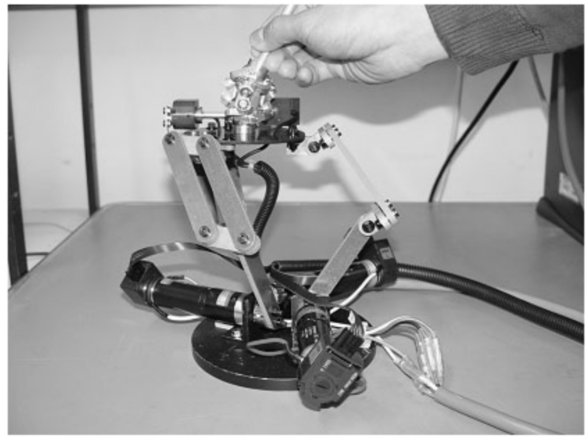


Fig. 3. High angle active link mechanism

Duralumin (specific gravity 2.8) is used for the link and the traveling plate because it is desirable that the moving part of the device is light-weighted to get a natural feeling of the input. Furthermore, the force is generated in the direction which always supports its weight to reduce an influence of the weight of the moving parts to a feeling of the input. The bearing is attached at the joints (18 places) of the links, and a smooth movement is realized. Various postures of the geometric modeling device are shown in the Fig. 4(a)-(b).



(a) Posture No.1



(b) Posture No.2

Fig. 4. Various postures of the geometric modeling device

The user grips the part of the pen attached to the device, and does input for the geometric modeling system. The sense in which a user touches through the tool such as a pen can be reproduced easily in comparison with the sense in which a human touches by the finger. Hence the pen type device can reproduce a better sense of reality by limiting its tactile sense range to the head point of the pen.

The geometric modeling device developed in this research equips three DC servo motors and five rotary encoders.
The input of the position and that of the posture from the device to the computer are measured with the rotary encoders. The rotation angle of each axis is input into the counter board connected to the PCI bus of the computer as a pulse signal, and a rotation angle is measured by counting its number of pulses.

The rotary encoder HEDS5540 (500 [pulse/rotation]) manufactured by Maxon motor is used for the delta type mechanism of the positional input part. This encoder is attached to the shaft of the DC servo motor whose gear head of the reduction ratio is 21:1. In consideration of the reduction ratio, the resolution about the axis of the rotation is 0.034 [°/pulse]. The rotary encoder UN1000 (1000 [pulse/rotation]) manufactured by Mutoh engineering inc. is used for the posture input part. The resolution about the axis is 0.36 [°/pulse].

Three DC servo motors are used for haptic rendering. The supply of electric power to the DC servo motors is controlled by inputting an analog signal between -5[V] to +5[V] from the DA board equipped with the computer to the DC servo amplifier, and a torque of arbitrary magnitude is generated. In this research we use a DC servo motor RE25 (Maxon motor, rated output 20[W], nominal voltage 18.0[V], breakdown torque 218[mNm]).

4. SOFTWARE SYSTEM

In this research the modeling and the painting operations are performed to objects defined with point-based geometry. The point-based geometry is a method to represent a geometric object by use of the point (surfel) with the information about its position, normal and color as a rendering primitive.

5.1 Modeling Process

The geometric modeling is performed by computing the Boolean operation between the tool object (tool) and the modeled object (work). The subtractive Boolean operation simulates the cutting process of the object. The additional Boolean operation simulates the modeling process which deforms the shape of the work object by adding clay to it.

The flow of the processing is as follows:

(1) As a preprocessing, the system builds an octree of the surfels defining the object.
(2) The inside-and-outside check is applied to all surfel of the tool and the work, and the attribute of whether to exist inside or outside of each object is attached to each surfel.
(3) The addition and deletion of the surfels depend on the attributes determined by the inside-and-outside check.

The technique proposed by Adams[6] is applied to the inside-and-outside check of Step (2). By repeating Steps (2) and (3), the shape of the object is modified interactively. In the case of cutting, the object after modeling can be created by removing surfel of the inside attribute of the work, and adding surfel of the inside attribute of the tool to the work in Step (3) as shown in Fig. 5. An intuitive modeling is possible by representing cutting resistance as tactile sense information to the user.

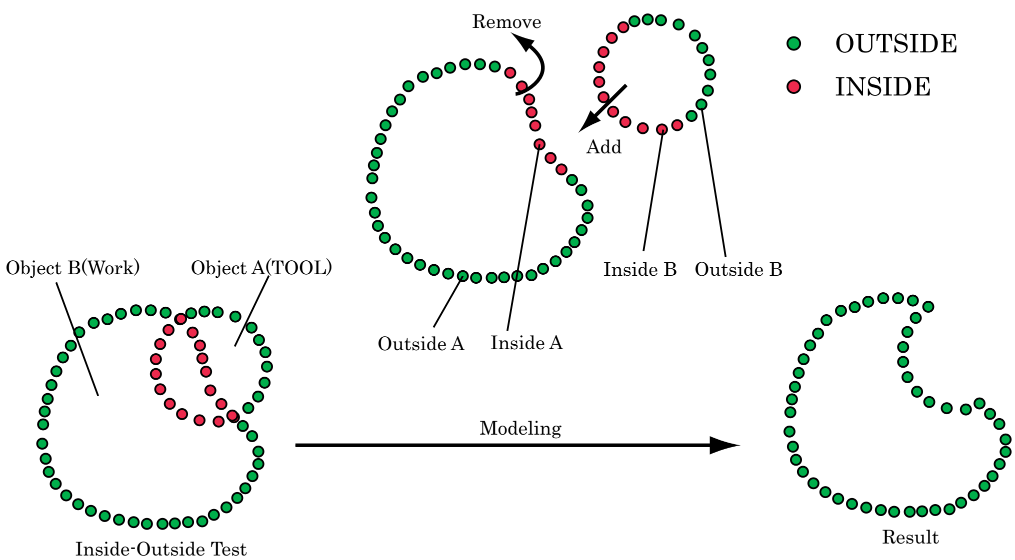
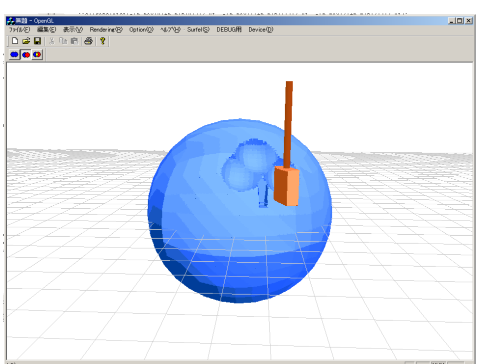
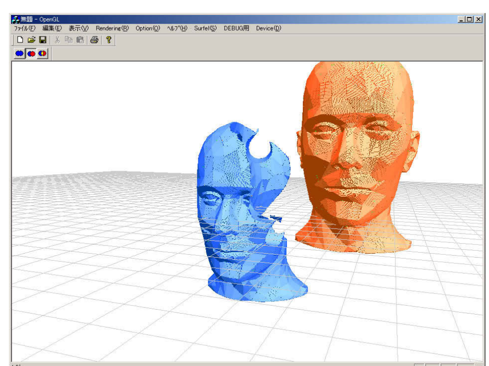


Fig. 5. Cutting



(a) Modeling example No.1



(b) Modeling example No.2

Fig. 6. Modeling process

5.2 Haptic Rendering

The algorithm to generate tactile sense depends on the modes: modeling and non-modeling. In the modeling mode, the objects can be deformed and in the non-modeling mode, the objects can not be deformed and the user can only touch them. The haptic rendering algorithm in the modeling mode generates the force proportional to cutting volume and the force proportional to speed. It is difficult to calculate volume cut by the tool precisely in point-based geometry. Therefore we use the number of surfels to be removed during the cutting operation as a cut volume. The haptic rendering algorithm in the non-modeling generates the force proportional to the number of surfels which penetrate into the object and the force proportional to speed. The magnitude of the force is calculated by the following expression:

$$|F| = k_p N + k_v |v|$$

where N is the number of surfels, and v is the speed of the tool object, and k_p and k_v are constants. The direction of force is given by that of the vector which is an average of the normal vectors of surfels of the work penetrating into the tool. The force proportional to speed restricts the movement of the tool to go out of the tool object if it is always applied while the tool object penetrates into the work. Therefore, only a speed element in the direction to penetrate into the work is added to the reactive force as the resistance force. For the calculation of the reactive force, only a speed in the direction to penetrate $(x_2 - x_1)$ without a speed in the direction to go outside $(x_3 - x_2)$ is computed in Fig. 7.

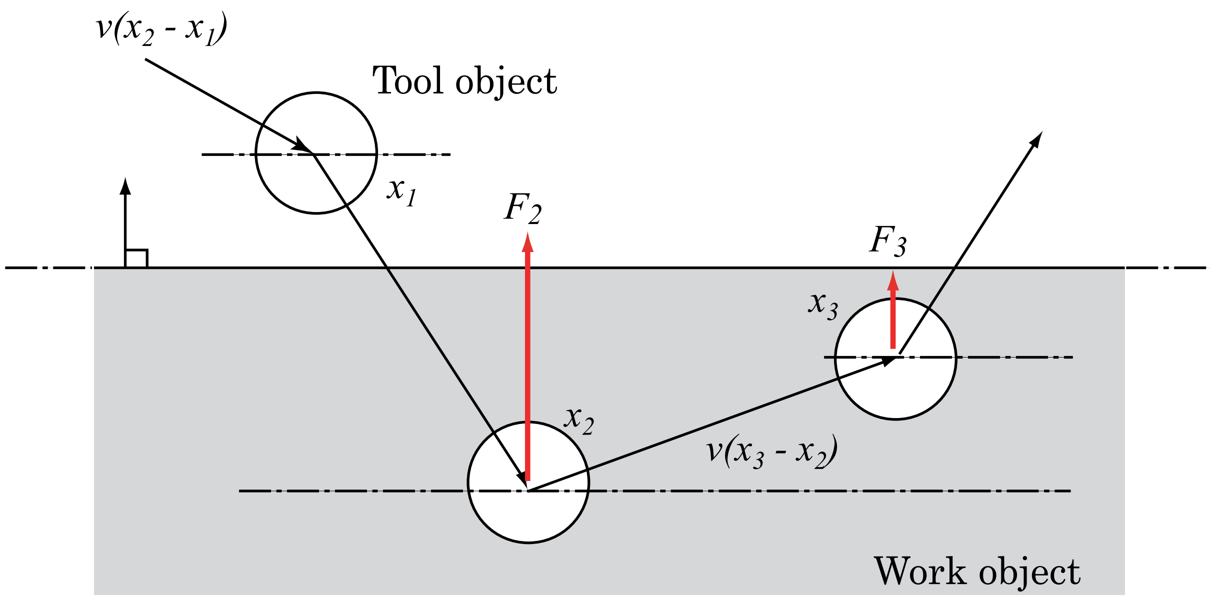


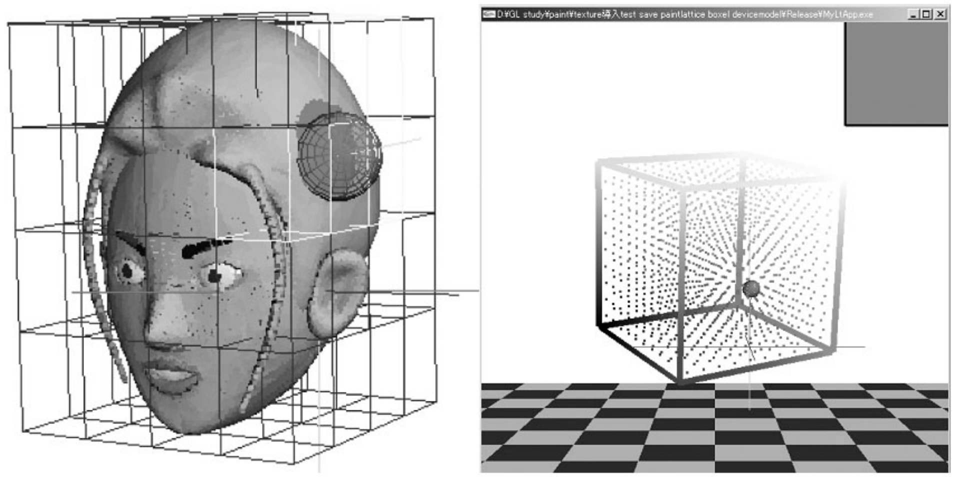
Fig. 7. Haptic rendering

5.3 Painting Process

In painting process (Fig.11), arbitrary colors can be applied and a texture can be pasted to the object. They can be done easily by using the three-dimensional user interface such as a 3D color palette (Fig. 8(b)) using the advantage of the 3-dimensional positional input of the device.

6. COMNCLUSIONS

In this research, the geometric modeling device which uses the parallel link mechanism has been developed, and the fine tactile sense representation is achieved. The system which can create 3D characters intuitively has been developed with the modeling and the painting software of 3-dimensional geometry using the newly developed device.



(a) Interface (b) Color palette

Fig. 8. Painting process

7. ACKNOWLEDGMENT

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