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FORCE DISPLAY SYSTEM FOR REALIZATION OF CUT-IN-FEELING OF VIRTUAL SHEET OBJECT BY SCISSORS

H. Wakamatsu, S. Aoyagi, K. Takahara and M. Yasuna
School of Allied Health Sciences,
Faculty of Medicine, Tokyo Medical and Dental University
1-5-45 Yushima Bunkyo-ku, Tokyo 113, JAPAN

ABSTRACT

A stereoscopic cutting of virtual object in a real space using a human binocular parallax is discussed. A scissors-type edged-tool with 2-degree of freedom is developed for the realization of reactive force feeling on the cutting into stereoscopically viewed virtual object. An image of sheet is given as a virtual object for cutting. The reactive force is provided for the tool, by which fingers obtain feeling of cutting according to given physical properties to the image. The stereoscopic cutting makes clear a trace of the cutting point of scissors characterized by a different color in a virtual object given as an image. This paper describes first the construction of a scissors-type edged-tool for cutting. Then, force display system is synthesized providing feeling of cutting of materials by the edged-tool according to their given properties.

Keywords: Stereoscopic cutting, Scissors, Virtual reality, Force display system

1 INTRODUCTION

A force display system is expected to have much effects and benefits in its possible applications to various fields as means of a human interface with an interactive sensory response to an operator in accordance with his action to virtual objects. It has been intensively aimed at to synthesize such a system in medical domain in which there exist various kinds of difficulties and constraints in manipulation and operation with actual tissues or organs. From this point of view, one of the present authors has proposed a cutting method of stereoscopic 3D image by stereoscopic 3D mouse cursor regarded as an knife [1-2] and a force display system with an edged-tool, by which direct cutting is possible with a reactive force on cutting of virtual objects [3-4]. Consequently, it became possible to feel reactive force of cutting by fingers with a visually direct recognition of a hand movement, which leads to the way of its application to the stereoscopic cutting of various kinds of stereoscopically viewed virtual objects such as hearts and brains in a real space. The cutting by knife, however, is not an only way for satisfactory cutting and other possible ways should be substantially studied for the application of human friendly cuttings to the new types of operation.

In the present study, it is therefore aimed at to realize reactive force, making clear physical mechanism of cutting of materials by scissors, with a substantial interpretation of cutting which is different from that by knife. Then, a human friendly force display system is synthesized to feel reactive force using this edged-tool without any particular constraint in its operation to cut virtual sheet object in a real space[5]. That will provide some possibilities to the simulation of surgical operations but also a kind of satisfaction and pleasure in feeling of cutting different materials associated with feeling by knife-type and/or saw-type edged-tools [3-6].
2 CONDITIONS AND ASSUMPTIONS FOR CUTTING BY SCISSORS

2.1 Reason for the introduction of scissors-type cutting device

Scissors are very commonly used for cutting in medical operations as well as knives and saws. They will provide different and substantial cutting from those by knives or saws. Thus, as a cutting device in the present study, such scissors are taken into consideration that have a fulcrum holding two blades in the middle, a grip as a stress point and a cross point of two blades as a point of action.

2.2 Materials to be cut

Here, paper-like plastic sheet is considered as a material to be cut, which can bend itself according to its distributed weight. Without any knowledge about physical properties of materials to be cut, however, attendance to the reality in its cutting cannot be realized, even scissors-type edged tool is made suitable for a force display system to give an operator reactive force quantitatively. It is thought that materials are described by physical properties such as density, viscosity, elasticity and plasticity. Hereby, only properties of density and elasticity are assumed in triangular mosaics to which plastic sheet is divided, in which viscosity is not taken into account.

Fig.1 Material represented by mosaics characterized by physical properties.

2.3 Approach to scissors-type edged-tool

For the simple discussion on the later synthesis of a force display system using scissors-type edged-tool, a material to be cut is always assumed in contact with a cross point of two blades on its cutting. Scissors are designed to move only in the direction against the object to be cut as illustrated in Fig.2. The lower blade of scissors is designed to keep its position in parallel to floor for easy calculation of cutting-in distance of blades using the rotational angle around their fulcrum. The cutting-in force felt by hand and/or arm is difficult to quantify in comparison with that by fingers. Therefore, the scissors are designed to be held by the prop on the platform car for easy analysis of force to fingers. That is, the reactive force on fingers is mainly discussed considering only unidirectional force to hand and/or arm.

Fig.2 Positional relation between scissors and virtual object to be cut.

2.4 Assumption on realization of reactive force

There can be thought the following two kinds of movements of scissors on cutting of a sheet:

1. Movement of two blades around their fulcrum without any forward and backward sliding movement of the body to sheet.
2. Forward sliding movement of the body to sheet without any rotational movement of blades.

The cutting of sheet by scissors consists of movements 1 and/or 2. In the present study, scissors are assumed to move according to only the movement 1, where their "movement of blades" and "movement of body" are taken into account in order to understand sensory and motor relation on cutting of a virtual object. The former implies opening and closing movements of blades, the latter the constraint of movement of scissors on their cutting of an object, although actual scissors can freely move in any direction.

Table 1 indicates reactive force given to blades and body of scissors at their states on cutting a sheet of paper in a restricted manner. It shows movement and reaction of scissors according to the positional relations of blades to a sheet of paper in three cases described by illustrations (0), (1) and (2). The body of scissors moves only in a forward or backward direction. It is, however, remarked that the body does not go forward on the cutting of paper as shown by illustration (2).
When a condition of crossing of paper and blades is satisfied, an operator gets a feeling of cutting where the body does not further move, but moves backward, if necessary, because the backward movement of scissors is not restricted on any states of scissors.

Table 1 Movement and reaction of scissors with positional relation to paper.

<table>
<thead>
<tr>
<th>Relation between paper and scissors</th>
<th>Reactive force on cutting</th>
<th>Constraint of scissors movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>(b)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>(c)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Thus, the feeling of cutting can be provided, even if a material to be cut is virtual sheet object, as long as the above state is realized, giving appropriate force according to the cutting-into positions of paper and blades of scissors.

It is here remarked that further is the cutting point of the scissors from their fulcrum, greater the force of cutting-into sheet, depending on different rotational moment of blades. The force exerted on two blades by viscosity on their opening after cutting is not considered which depends on the contact area of blades with materials to be cut.

There are still lots of influential factors on the feeling of cutting, such as shapes and thickness of blades, position of grip and fulcrum, cutting speed of scissors, on the other hand, properties such as density, viscosity, elasticity and plasticity of materials to be cut as described before. It is, however, main purpose of this study to realize well attendance and good feeling of cutting as much as possible by using an edged-tool as similar as possible to the actual one with no particular constraint in its operation.

3 DESCRIPTION OF CUTTING DEVICE

3.1 Outline of scissors-type edged-tool

Figure 3 shows a cutting device with some structural restrictions based on the assumption of cutting. The cross point P of two blades is a cutting point into stereoscopically viewed image. As scissors mounted on the wheel (scissors-vehicle) move in parallel with x-axis, the coordinate of point of action P can be calculated from displacement $X_R$ and rotational angle $\theta$ of a fulcrum of scissors. As an unidirectional movement of a scissors-vehicle is transformed into rotations of shaft A, its position $X_R$ is calculated using output from encoder connected to shaft A. The shaft C is connected to the shaft of ratchet wheel through electromagnetic clutch. Therefore, movement of the vehicle is restricted, when a cutting point agrees with a cross point of two blades. The force on operation of scissors is determined by friction of two blades and reactive force on cutting into an object. Hereby, the force is given against rotational direction by setting

![Fig.3 Outlook and movement of cutting device.](image-url)
electromagnetic brake to the rotational axis of scissors to realize feeling of cutting, when scissors are operated by fingers. As understood by Fig.3, weight of an edged-tool with an electromagnetic brake is not recognized because of the prop of scissors, but only a friction of the_blade and resistance given by electromagnetic brake are perceived by an operator. The movable domain of the fulcrum of an edged-tool is determined 150-700[mm] measured from CRT screen, considering that an operator can readily manipulate it to reach a virtual object without distortion of its 3D image. The height of prop of scissors is adjusted to keep their fulcrum to that of the center of CRT screen which is given as 247[mm]. The length of blades from their fulcrum is 75[mm] which greatly affects the reactive force on cutting-in of the sheet and the range of their rotational angle is given 50 [deg].

3.2 Movement of point of action

The cutting of an object is interpreted as a physical phenomenon, which results from the movement of a point of action P to P' by changing of \( \theta \) to \( \theta' \) of the angle given by central lines \( l \) and \( m \) of the two symmetrical blades as illustrated in Fig.4.

\[
d = S - S' = A \sin \alpha \left( \cot(\alpha + \theta/2) - \cot(\alpha + \theta/2) \right)
\]

(2)

If the distance \( X_R \) of a fulcrum \( R \) of scissors is measured from the origin given on the center of CRT screen, the coordinate of point \( P \) can be calculated from the distance \( X_R \) and rotational angle \( \theta \) of a fulcrum of scissors with their fixed \( y \) and \( z \) coordinates.

4 FORCE DISPLAY SYSTEM FOR CUTTING VIRTUAL OBJECT

4.1 Configuration and principle of the system

The force display system, by which providing force can be controlled, has a configuration as illustrated by Fig.5, combining a previously discussed edged-tool with a computer, liquid crystal glasses, controllers, DC power supply and so on.

A computer acquires signals from encoders connected to shafts \( A \) and \( R \) according to the movements of a scissors-vehicle and blades. The distance \( X_R \) of fulcrum from CRT and the rotational angle \( \theta \) calculated from the pulses of encoders gives a coordinate of point of action \( P \) of an

Fig.4 Movement of a point of action \( P \) on cutting by scissors.

Let the angle between an edge and a central line of each blade be given by \( \alpha \), and \( QR = A \), then

\[
S = A \sin(\theta/2)/\sin(\alpha + \theta/2)
\]

(1)

Fig.5 Configuration of force display system for cutting virtual object given as stereoscopically viewed image.
edged-tool. On the other hand, a computer sends 3D image data for stereoscopic view using binocular parallax and signals which control driving voltages of electromagnetic brakes connected to shafts B and C in accordance with a coordinate of a point of action P. That is, when a point P satisfies cutting condition of a virtual object by scissors, the corresponding reactive force is feedbacked to an operator by an electromagnetic brake in a direction against rotation of the shaft R.

4.2 Comments on stereoscopic cutting and realization of feedback force

There exist some limitations of alternative shuttering of liquid crystals and 3D images for binocular parallax and dynamic calculation of coordinate of cutting point P, because a speed of calculation is very dependent on a computer and visual characteristics of eyes. Therefore, the following operations are successively required in a time as short as possible for the realization of stereoscopic cutting and force feedback using the pertinent force display system:

① Calculation of coordinate of point of action P of a cutting device measuring position of fulcrum and angle between two blades.
② Judgment of satisfaction of cutting condition
③ Driving of electromagnetic brakes and clutch when cutting device agrees the cutting condition of virtual objects.
④ Reconstruction of 3D images of virtual object with a colored cutting line for binocular parallax.

The time to complete the above operations is, however, dependent on the complicity of shape of a virtual object. Therefore, only a sheet of paper with a simple shape is taken into account in the present study so that the above operations may be performed in a limited short time.

4.3 Cutting condition and coordinate of cutting point

Figure 6 gives parameters-relation when a virtual sheet object is cut by a scissors-type edged-tool according to the previously given conditions. Hereby, a virtual plane \( G (z=0) \) drawn as a figure with practically no thickness by triangular mosaic method (cf. Fig.1) is assumed perpendicular to \( yz \)-plane. As a cutting device moves only in a direction perpendicular to CRT screen, the path of an edged-tool is given by \( y=z=0 \).

![Fig. 6 Parameters-relation for cutting conditions.](image)

Let the closest point to CRT screen given by a cutting line on the plane \( G \) and the point of action P of scissors be indicated by \( X_m \) and \( X_p \) respectively on the operation of the force display system. The accuracy of determining the coordinate of cutting point is dependent on the resolution of encoders. If \( X_m = X_p + \varepsilon \) (\( \varepsilon \) is a sufficiently small positive number) is satisfied on the cutting of a virtual sheet object, then feedback force is given to the shaft R by driving an electromagnetic brake on the shaft B and an electromagnetic clutch on the shaft C to restrict forward movement of a scissors-vehicle. Thus, the system indicated by Fig.5 gives reactive force to an operator according to values determined beforehand from physical properties given to triangular mosaics of a virtual object, when he makes an action to cut into a stereoscopically viewed virtual sheet object by a cutting device.

Considering the simple discussion of feedback force, mechanical properties of materials to be simulated are restricted to the ones characterized only by density and elasticity as mentioned previously. As the force increases proportional to the distance from the fulcrum shaft R, the reactive force \( F = k \rho \) is introduced where \( k \) is a constant depending on the physical properties of density \( \rho \) and elasticity \( E \), and \( x \) is distance of cutting point from the shaft R.
5 SUMMARY

An edged-tool without any particular constraint for its manipulation has been realized as a cutting device which is similar to the actual scissors used in everyday life. In addition to it, the force display system has been synthesized to realize reactive force using the developed edged-tool. The stereoscopic cutting of a stereoscopically viewed virtual object by the system has been confirmed to give an operator satisfactory attendance to the reality, as he can experience smooth change in reactive force on the cutting of a virtual sheet object. The structure of present edged-tool has been also practically confirmed to have no particular problem comparing ordinary function and structure of actual scissors.

In the present case, only the unidirectional motion of the vehicle has been taken into account, because it is pretty complicated to know a force to hand and/or arm together with a feedback force to fingers on its direction change in motion. This restriction concerning the motion of scissors does not damage essence of reactive force to the fingers, because materials to be cut can be regarded only to change their direction in motion when scissors change their proceeding direction to some extent. For smooth application of the force display system to various kinds of simulation, it is also important to remove such a restriction as a fixed lower blade of scissors. For this purpose, it is necessary to measure their relative position and to calculate the proceeding distance of the point of action by suitable methods.

In order to realize the more attendance to the reality, the scissors-type edged-tools are further required to have independent and self-contained mechatronic functions including radio-communication with computer, driving of brakes and sensing of their position.

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