Modeling Virtual Hands with Haptic Interface Device

Somsak Walairacht, Keita Yamada, Yasuharu Koike, and Makoto Sato

Precision and Intelligence Laboratory,
Tokyo Institute of Technology
4259 Nagatsuta, Midori-ku, Yokohama, 226-8503, JAPAN
{somsak, kyamada, koike, msato}@pi.titech.ac.jp

Abstract

For direct manipulation environment with force feedback, we propose a kind of string-based two-handed multi-fingers haptic interface device. The system can sense the positions of three fingertips and wrist on each of the user's hand. Force feedback can be perceived when the position of the finger comes into contact with the virtual object. We explain in detail about the algorithms used in the force feedback generation and the calculation of the positions of the user's hands. Then, we have modeled images of virtual hands from positions on the user's real hand measured by the system. Method of hand shape modeling is presented in this paper.

Key words: virtual reality, direct manipulation, haptic interface device, modeling virtual hand

1. Introduction

The haptic interface device used for modeling the virutal hands is an improved version of the SPIDAR (SPace Interface Device for Artificial Reality), originally developed by M. Sato et al. SPIDAR is a kind of motor-string-based haptic display system. It has many advantages such as, simple mechanism, safe, light-weighted, and moving free. The system allows the user to directly manipulate virtual object in the virtual environment. SPIADR has been continuously developed and applied to many fields of research and studies.The proposed system is called SPIDAR-8. Beside of the advantages mentioned above, the characteristic of this improved system is a two-handed multi-fingers human interface device with force feedback. The user can perform direct manipulation with the collaborative works of both hands by using this system.

In this paper, we focus our works on the modeling of virtual hands. A hand consists of many joints and links. There are 26 degrees of freedom found on one hand. Since, our device can provide 4 information of positions on one hand. Therefore, it is very difficult to estimate 26 parameters from 4 known positions. A criterion is setup to reduce hand's DOF. Then, we calculate the changes of joint angles of the fingers from the changes of fingertips positions. Finally, we can estimate the shape of the virtual hands.

The content of this paper is divided into two main parts. The first part mentions about the detail of the system. We have presented the position measurement of the user's hands and the algorithms used to generate force feedback. While in the second part, we have explained about methods of modeling virtual hands from positions on the real hands of the user measured by using the system.

2. System Overview

Fig. 1 shows the overview of the system. SPIDAR-8 uses DC motors with rotary encoders, pulleys, and strings to measure the positions on the real hands and generated force feedback. The motor is mounted with rotary encoder at its back. Totally twenty-four motors are attached to the rectangular cubic frame of light-weighted aluminum pipes. A string is wound around a pulley, which is connected to a motor. Three strings of three motors from each corner of the frame are connected together and attached to a kind of attachment device. The system allows both left and right hands to be used at the same time. On each side of the hand, the user will wear the fingertip attachment devices on the thumb, index finger, middle finger and attaches three strings to the wrist. Position of the user fingertips and wrist can be measured by the length of the strings. At the same time, the system uses the tensions of the strings to generate force feedback at the user’s fingertips.

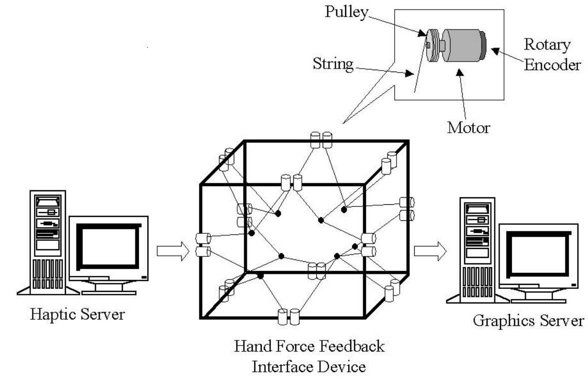


Fig. 1 System overview

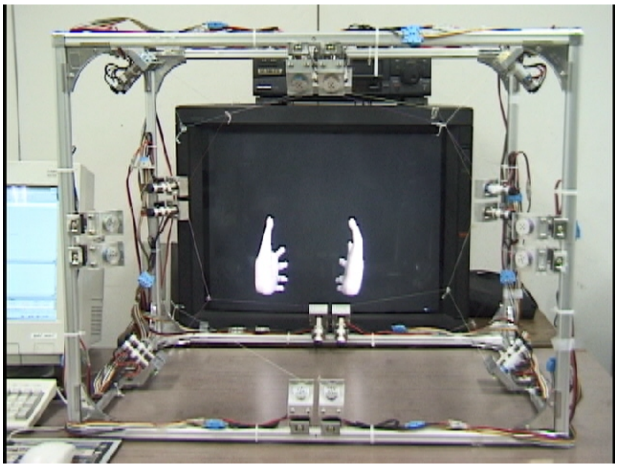


Fig. 2 SPIDAR-8

3. Position measurement

The system measures the positions on the user's hands from the length of strings. Positions on one of the user's hand are referred to the fingertip position of thumb, index finger, middle finger, and a position on the wrist. The length of a string is known by reading the values from the rotary encoder. For any positions on the user's hand, the coordinates of three motors are already known and when the length of three strings are given, that position can be calculated.

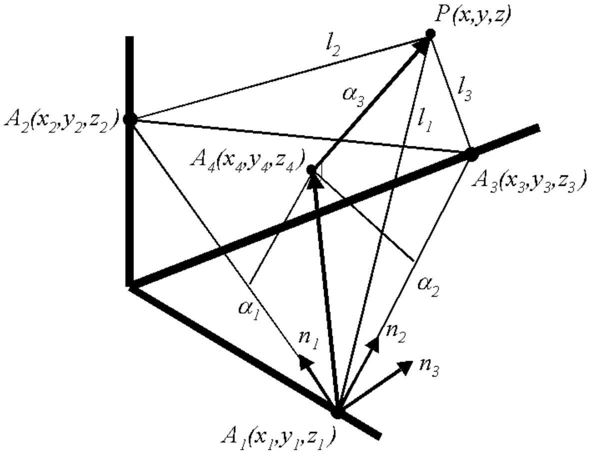


Fig. 3 Position measurement

From Fig. 3, let $P(x,y,z)$ be one of the position on the user's hand. Three motors are located at the points $A_1(x_1,y_1,z_1)$, $A_2(x_2,y_2,z_2)$, and $A_3(x_3,y_3,z_3)$. If the length of three strings, $l_i\ (i=1,2,3)$, are given, we have

$$l_1^2 = \|P - A_1\|^2 \tag{1}$$

$$l_2^2 = \|P - A_2\|^2 \tag{2}$$

$$l_3^2 = \|P - A_3\|^2 \tag{3}$$

Vector n_1 is a unit vector along the segment A_1A_2 and vector n_2 is a unit vector along the segment A_1A_3.

$$n_1 = \frac{A_2 - A_1}{\|A_2 - A_1\|}$$

$$n_2 = \frac{A_3 - A_1}{\|A_3 - A_1\|}$$

and cross product of n_1 and n_2 gives

$$n_3 = n_1 \times n_2$$

A point $A_4(x_4,y_4,z_4)$ is orthogonal projection of point P onto the triangle plane of $A_1A_2A_3$. The projections of vector A_4-A_1 on A_2-A_1 and A_3-A_1 are α_1 and α_2 respectively. The orthogonal distance from P to the plane $A_1A_2A_3$ is α_3. Distance from point A_1 to point A_2 is d_1 and from A_1 to A_3 is d_2. Eq. 1,2 and 3 become

$$l_1^2 = \|\alpha_1 n_1 + \alpha_2 n_2\|^2 + \alpha_3^2 \tag{4}$$

$$\begin{aligned} l_2^2 &= \|P - A_1 - (A_2 - A_1)\|^2 \\ &= \|\alpha_1 n_1 + \alpha_2 n_2 - d_1 n_1\|^2 + \alpha_3^2 \end{aligned} \tag{5}$$

$$\begin{aligned} l_3^2 &= \|P - A_1 - (A_3 - A_1)\|^2 \\ &= \|\alpha_1 n_1 + \alpha_2 n_2 - d_2 n_2\|^2 + \alpha_3^2 \end{aligned} \tag{6}$$

We can calculate position of point P from Eq. 7.

$$P = A_1 + \alpha_1 n_1 + \alpha_2 n_2 + \alpha_3 n_3, \quad \alpha_3 \ge 0 \tag{7}$$

Since $\quad A_4 - A_1 = \alpha_1 n_1 + \alpha_2 n_2$

Eq. 7 can be rewritten as

$$P = A_1 + (A_4 - A_1) + \alpha_3 n_3, \quad \alpha_3 \ge 0 \tag{8}$$

Solving Eq. 4, 5 and 6, we get the values of α_1 and α_2. Substitute these values into Eq. 8, the position of point P which is a finger position can be obtained.

4. Force feedback generation

Force feedback at the fingertip of a finger is the resultant of the tension forces of three strings as shown in Fig. 4. By controlling the amount of the electric current entering the motors, force feedback can be generated.

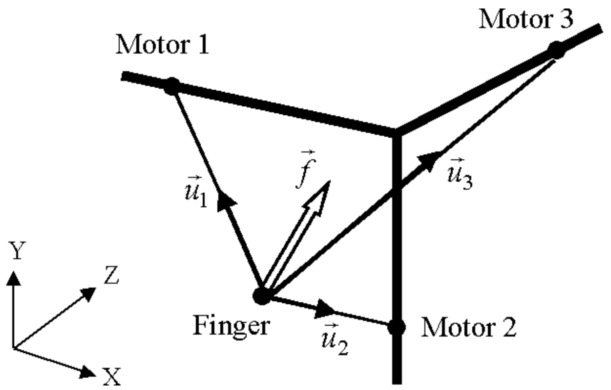


Fig. 4 Force generation using three strings

Let the resultant force vector be *f* and the unit vectors of tension t_i be u_i $(i=1, 2, 3)$ then, *f* can be expressed as in Eq. 9.

$$\vec{f} = \sum_{i=1}^{3} t_i \vec{u}_i \tag{9}$$

Fig. 5 shows an example of the positive triangular cone of force of one finger. There is one drawback on our system that is the limitation of displaying forces in all direction. Force feedback for each finger can be displayed completely only when the direction of resultant force lies inside its own positive cone.

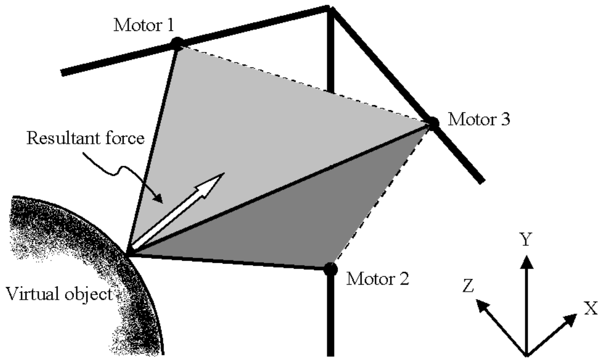


Fig. 5 Positive cone of force

Nevertheless, we have tried to reduce this limitation by expanding the direction for displaying force of each finger. In the case that the resultant of any finger, which has direction pointed out of the positive cone, the force vector will be projected back onto its positive cone. Then, the resultant force is recalculated from the tension of any positively projected strings. By this way, the system can display suitable force feedback covering in the wider direction. It is shown as in Fig. 6 that force space of each finger after this process can be divided into three different areas. First, the area that $f=f_0$ is the area that the system can completely display force. Next, the areas of $f=Proj(f_0)$ are the areas that the system can partly display forces. And, lastly, the area of $f=0$ is the area where the system cannot display any force.

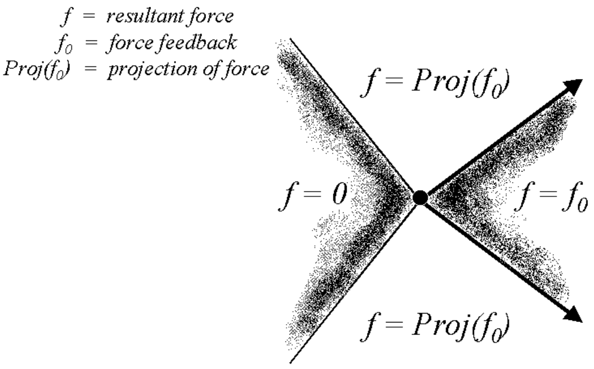


Fig. 6 Force space

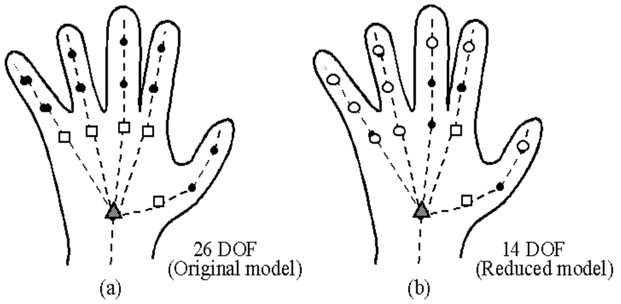
5. Modeling virtual hands

Human's hand has many joints and links. Each joint has different degree of freedom. There are totally 26 degrees of freedom found on one hand as shown in Fig. 7(a). Since SPIDAR-8 can provide 4 sets of 3D value of position on one hand, and it is necessary to estimate 26 parameters from only 4 known positions. To reduce the processing works, we have reduced the DOF of hand from 26 to 14 as in Fig. 7(b) with the following criterion.

Criterions used to reduce hand's DOF are

1. Since the joint close to the fingertip and the next joint are bent by the same tendon, we consider the ratio of joint angles between these two joints to be constant.

2. Joint angles of ring finger and little finger are assumed to be in proportion to joint angles of middle fingers.



Joint	Degree of freedom
○	0 (be in proportion to other joint angle)
●	1
□	2
▲	6 (whole hand posture and position)

Fig. 7 Model of hand

Procedures for hand shape estimation are as follow.

1. Measure position of fingertips and wrists of the real hands of the user by using SPIDAR-8
2. Positions of the hands are determined by positions of the wrists measured by the system.
3. Calculate the changes of joint angles of the fingers from the changes of the fingertip positions.
4. Model hand shape from fingertip positions measured by SPIDAR-8 and the calculated by joint angles.

Let the fingertip positions of thumb, index finger, and middle finger be

$$P = (P_0, P_1, ..., P_M) \tag{10}$$

and the joint angles of the fingers be

$$\theta = (\theta_0, \theta_1, ..., \theta_N) \tag{11}$$

Then, we can say that

$$P = f(\theta) \tag{12}$$

The changes of fingertip positions between positions measured by the system and positions of the virtual hands are used to calculate the changes of joint angles of the fingers. From Eq. 12, the function *f* can be expressed as the jacobian of joint angles as in Eq 13.

$$dP = J(\theta)d\theta \tag{13}$$

To calculate inverse matrix of jacobian in Eq. 14, we use Moore-Penrose pseudo-inverse matrix as in Eq. 15.

$$d\theta = J(\theta)^{-1}dP \tag{14}$$

$$A^+ = \begin{cases} (A^tA)^{-1}A^t, & \text{rank of } A = M \\ A^t(AA^t)^{-1}, & \text{rank of } A = N \end{cases} \tag{15}$$

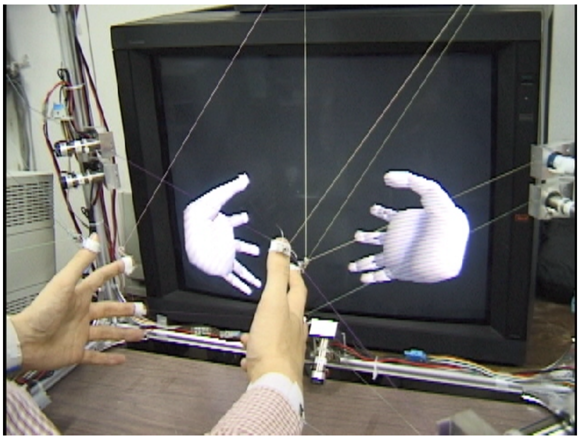


Fig. 8 Virtual hands

7. Conclusion

We propose a new human interface device for both hands direct manipulation in the virtual environment. The system is a kind of string-based two-handed multi-fingers haptic interface device. Positions of three fingertips and a wrist on each hand are measured at all time. When position of the fingers come into the contact with the virtual objects, the system generates force feedback at the user's fingertips. We use positions on the real hands measured by the system to model shape of the virtual hands. In this paper, the explanations of algorithms used in the force feedback generation, the calculation of positions of user's hands, and the method of modeling virtual hands are presented.

References

1 Iwata, H., T. Nakagawa, and T. Nakashima, "Force Display for Presentation of Rigidity of Virtual Objects", Journal of Robotics and Mechatronics, Vol. 24, No. 1, pp. 39-42, 1992.

2 Bouzit, M., P. Richard, and P. Coiffet, "LRP Dextrous Hand Master Control System", Technical Reposrt, Laboratoire de Robotique de Paris, pp. 21, January 1993.

3 Burdea, G., D. Gomez, N. Langrana, E. Rokros, and P. Richard, "Virtual Reality Graphics Simulation with Force Feedback", International Journal in Computer Simulation, ABLEX Publishing, Vol. 5, pp. 287-303, 1995.

4 Y. Hirata and M. Sato, "3-Dimensional Interface Device for Virtual Work Space", Proc. the 1992 IEEE/RSJ International Conference on IROS, 2, pp. 889-896, 1992.

5 M. Ishii and M. Sato, "3D Spatial Interface Device Using Tensed Strings", PRESENCE-Teleoperators and Virtual Environments, Vol. 3 No. 1, MIT Press, Cambridge, MA, pp. 81-86, 1994.

6 S. Hasegawa, M. Ishii, M. Sato, and Y. Koike, "Haptic Interface Protocol for Complex Dynamic Virtual World", The seventh International Conference on Artificial Reality and Tele-existence, pp. 83-89, 1998.

7 S. Kim, S. Walairacht, M. Ishii, M. Sato, and Y. Koike, "Personal VR System for Rehabilitation to Hand Movement", The seventh International Conference on Artificial Reality and Tele-existence, pp. 102-108, 1998.

8 K. Ishibuchi, K. Iwasaki, H. Takemura, and F. Kishino, "Real-time Vision-based Hand Gesture Estimation for Human-Computer Interfaces", Transactions of IEICE D-II Vol. J79-D-II No. 7, pp. 1218-1229, 1996.

9 K. Funahashi, T. Yasuda, S Yokoi, and J. Toriwaki, "A Model for Manipulation of Objects with Virtual Hand in 3D Virtual Space", Transactions of IEICE D-II Vol. J81-D-II No. 5, pp. 821-831, 1998.