

Performing virtual surgery with a force feedback system

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Abstract

We are developing a surgery simulator which would enable surgeons to perform various kinds of surgical maneuvers in virtual space using VR techniques. Furthermore this system would be able to manipulate patient oriented 3D structures of the body as elastic objects in real time. The system employs a force feedback device that supplies the user with a sense of touch. As the device is attached to right and left hands, both of the user's thumbs, forefingers and middle fingers can feel the force and elasticity of skin and organs when pinched or compressed. The deformation of which is observed simultaneously on a real time 3D image.

1. Preface

Numerous studies show that surgery simulation is one of the largest applications of medical virtual reality ⁽¹⁾⁻⁽⁶⁾. In 1998 we presented our virtual surgery system equipped with force feedback functions in the ICAT97 ⁽⁷⁾. In the former paper, we presented our trial to obtain a sense of touch with the patients' organs in a virtual space. In this paper, we would like to present the results of the extended project. This system permitted physical manipulation of elastic organs utilizing force feedback device attached to each users hand.

2. Elastic organ models for the system

In order to reproduce an elastic organ appropriate for our system, we developed a sphere filled model method instead of applying the finite element method. The sphere filled method reconstructs a patient's organs as a surface model filled with small elements. The radius of each sphere is identical and they are filled up at a face-centered lattice in the organ model. The external forces generated by the users' fingers or tools displace the contacted element spheres. Those displaced element spheres in turn displace the surrounding spheres until the shape of every sphere in the organ ultimately changes. The new location of the element sphere determines the new altered surface of the organ models. The sum total of the magnitude and direction of the displaced element spheres can be used as a parameter of force to drive the force feedback system in order to create a sense of touch. If the external force exerting pressure on the organ ceases, the element spheres realign in their original position and the organ shape recovers its original shape much like an actual elastic organ.

We have improved this system primarily in two areas; final processing speed and system responsiveness. At first, we enhanced the efficiency of element sphere displacement calculation. Second, we enhanced the efficiency to calculate any interference from neighboring organs. We also attempted to correspond the performance in order to grasp the organ surface at a pinpoint. With the former system, precision was limited to an area equivalent to the mass held between 2 or 3 fingers. In other

word we couldn't grasp precise points such as those located at the middle part of a polygon of the organ model's surface. To overcome this limitation we subdivided the polygon at the location of the pinch point and then accurately generated an identical point located at the work position. We used a high-speed graphic workstation Onyx Reality Engine² and infinity reality (Silicon Graphics Inc.) for this system. The communication and data transportation networks between the graphic workstation and force feed back devices are constructed by the Internet.

3. Force feedback device for both hands

When considering the virtual surgery system with sense of touch for practical use, it is important to realize that the system possesses a facility to generate a physical sense of touch unlike those imitated by sound or a mechanical vibration. The user, in particular, requires a perception of the organ surface's elasticity or the weight of the organ tissue's mass. In order to provide these facilities in our force feedback device, we needed to create the following two mechanisms. First, we had to erect a system able to continuously and accurately measure the users' hand movements and that worked in conjunction with the control manipulator system. Second, we had to build a force control manipulator for each finger. Especially in the case of surgical works, we need accuracy in each finger's force control manipulators. However, if we had built a long manipulator sufficient to cover the surgical work area, its sensitivity would have decreased due to its own weight. Furthermore, complicated finger action may have interfered with an adjacent manipulator. If we had shortened and consequently reduced the weight of the force feedback manipulators, the user's work area would have become smaller than the work area for surgical manipulation. In light of these problems we designed a structure that fixed the short and light force feed back manipulators to the top (distal part) of the motion control manipulator which covers a larger work area. Fig.1 shows the basic composition of the force

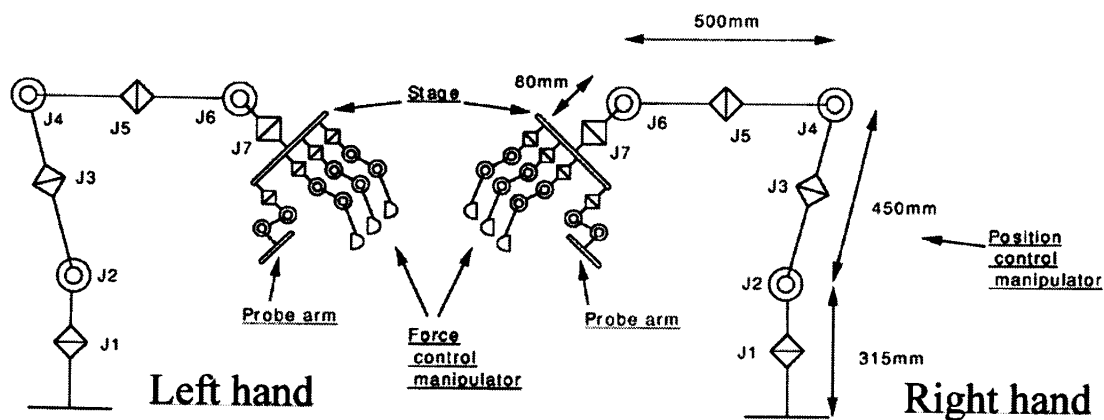


Fig.1 Block diagram of the force feedback device

feedback device. Both right and left force feedback devices have the same internal structure. The force feedback manipulator for the left hand is a mirror image of that of the right hand. On both hands, the force control manipulator producing the sense of touch is attached to the thumbs, forefingers and middle fingers of the right and left hands respectively.

4. Results

4-1 The elastic organ model

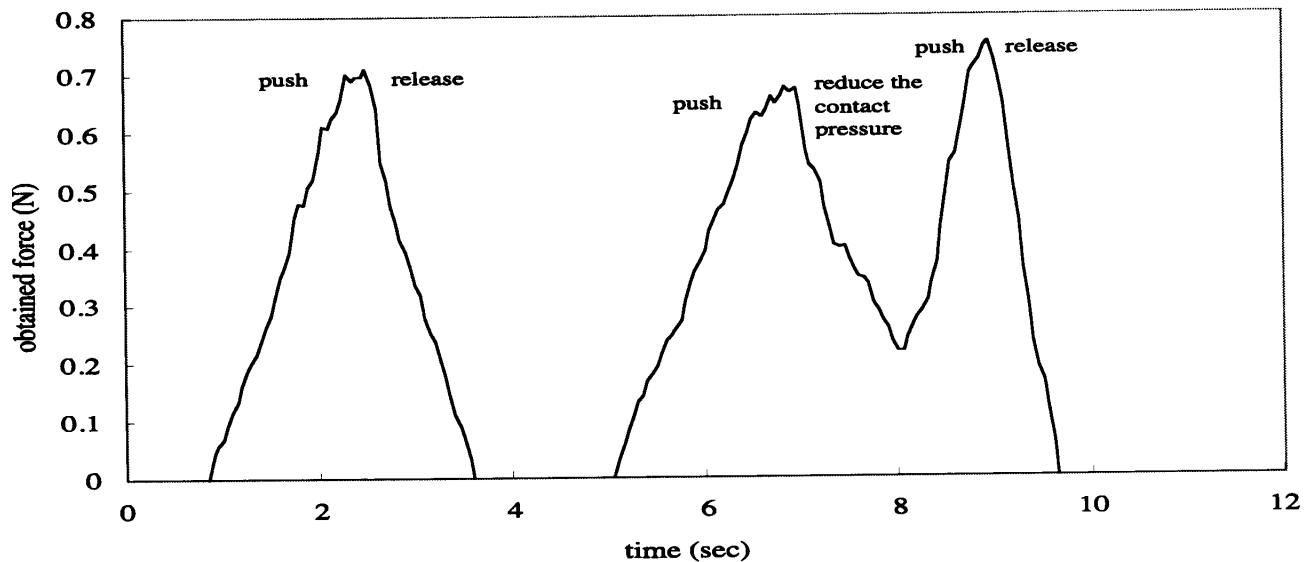


Fig.6 Time sequential change of the obtained force to a forefinger by the force controlled manipulator

5 Discussion

5-1 Elastic organ model

Although we made limitations on the diameter of the element spheres and the depth to which the spheres are movable (limit layer of spheres), we did make it possible to handle elastic organ models which possess 3D anatomical structures of the patient in real time. Thus, we would like to emphasize our method's merits as compared to those of spring models⁽⁸⁾⁽⁹⁾ or finite elements⁽¹⁰⁾⁽¹¹⁾. At first, (1) It is possible to construct an organ model semi-automatically unlike the considerable manual and pre-process work required with spring or finite elements. However, in our case, the model construction process can be completed by determining the organ contours and filling them with element spheres. (2) These procedures could be applied to neighboring organs and soft tissues (see Fig.2a,b). Thus, contact with neighboring organs is possible without specially calculating the interference with neighboring soft tissues. (3) As deformation is determined by the repetition of a simple calculation of element sphere movement, it is possible to obtain high speed performance. (4) Because the number of displaced element spheres is stable, it is possible to keep the organ's definite volume without any special calculations. (5) The direction and magnitude of the sense of touch is easily obtained by the integration of displaced element spheres. Therefore, it is possible to generate the sense of touch in real time because response speed is not effected by the number of fingers touching the organs.

5-2 Force feedback system when equipped to each hand

We would like to point out the following merits of our force feedback devices. (1) We obtained good mobility and low inertia from the finger manipulators fingers by shortening the length of the force feedback manipulators. (2) Complicated finger actions do not interfere with each other due to the base positioning of the force feedback manipulators on the opisthenar. (3) It was possible to obtain sufficient work space by changing the length of the motion control manipulator. Though the length of the force feedback manipulators was short, it was possible to obtain a large work space with good mobility. This was accomplished by tracking the hand movement rapidly with a motion control manipulator that loaded the force feedback manipulators at its distal part. Finally we obtained

a 400mm square work space which in our opinion is adequate to perform various surgical maneuvers.

5-3 Assessment of the total system

Using our system, we were able to physically manipulate an object that included skin surfaces and a liver model at a speed of 7 to 14 frames /sec. Also the user's three fingers on both the right and left hand were able to perceive a sense of touch through interactive actions. We are going to develop this system in order to perform complicated surgical maneuvers in various parts of the body. We believe that these kinds of VR simulators will be helpful for clinical surgery planning and for educational medical training.

References

- [1] Satava RM: Virtual reality surgical simulator, *Surgical Endoscopy*, 7:203-205, 1993.
- [2] Suzuki. N, Takatsu. A, Kita. K, Tanaka. T, Inaba. R, Fukui. K: Development of a 3D image simulation system for organ and soft tissue operations.: Abstract of the World Congress on Medical Physics and Biomedical Engineering 1994; 39a: 609.
- [3] Robb RA, Hanson DP: The ANALYZE software system for visualization and analysis in surgery simulation. In: *Computer Integrated Surgery*, Eds. Steve Lavalley, Russ Taylor, Greg Burdea and Ralph Mosges, MIT Press, 1995, pp.175-190.
- [4] Robb RA, Cameron B: Virtual Reality Assisted Surgery Program. In: *Interactive Technology and the New Paradigm for Healthcare*, Eds., R. Satava, et al., Vol. 18, 1995, pp.309-321.
- [5] Kikinis R, Langham Gleason P, Jolesz FA: Surgical planning using computer-assisted three-dimensional reconstructions. In: *Computer Integrated Surgery*, Eds. Russel Taylor, Stephane Lavalley, Grigore Burdea, and Ralph Mosges. MIT Press, 1995, pp.147-154.
- [6] N. Suzuki, A. Hattori, A. Takatsu: "Medical virtual reality system for surgical planning and surgical support", *J. comput. Aided Surg.*, 54-59, 1(2), 1995.
- [7] T. Ezumi, N. Suzuki, A. Takatsu, T. Kumano, A. Ikemoto, Y. Adachi, A. Uchiyama: "An Elastic Organ Model for Force Feedback Manipulation and Real-time Surgical Simulation", *ICAT'97*, Eds: S. Tachi et al., pp.115-121, The Virtual Reality Society of Japan, 1997.
- [8] D. Terzopoulos and K. Fleischer: "Modeling inelastic deformation: Viscoelasticity, plasticity, fracture", *Computer Graphics*, vol.22, NO.4, pp.269-278, 1988.
- [9] A. Norton, G. Turk, B. Bacon, J. Gerth, and P. Sweeney: "Animation of fracture by physical modeling", *The Visual Computer*, vol.7, pp.210-219, 1991.
- [10] H. Delingette: "Simplex Meshes: a General Representation for 3D Shape Reconstruction", Technical Report 2214, INRIA, Sophia-Antipolis, France, 1994.
- [11] S. Cotin, H. Delingette, M. Bro-Nielsen, N. Ayache, J.M. Clement, V. Tasseti, J. Marescaux: "Geometric and Physical Representations for a Simulator of Hepatic Surgery", *MMVR4 Health Care in the information Age*, Eds: H. Sieburg, S. Weghorst, K. Morgan, IOS Press and Ohmsha, pp.139-151, 1996.