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Virtual surgery simulator with force feedback function

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Abstract We developed a surgery planning system using virtual reality techniques which allows us to simulate incision of skin and organs which respond as elastic objects with surgical tools in virtual space. We also attempted to add a feedback function that responds to the pressure of the operator's hand using force feedback device.

1. Introduction

We have been developing a virtual surgery system that enables the performance of surgical maneuvers on an elastic object, whose structure has been obtained from a patient. We have proposed a so-called "sphere-filled model" to obtain the numerical value for force feedback manipulation and developed a force feedback manipulator attached to the thumb, forefinger, and middle finger of the operator.

2. Method

2-1. VR surgery simulation system

We tried to endow our system with the following features. (1) reality, to represent the accurate and detailed shape of the patient's organ and to allow the organ to be deformed, (2) real-time simulation, to handle the organ model in real-time, (3) ability to perform quantitative deformation, (4) accurate representation of the organ's inner structure, (5) ability to manipulate (push, pick, pinch, incise, and excise) the organ model by hand or with surgical tools in virtual space, (6) ability to connect it easily to the force feedback device and to obtain and process certain values for force feedback.

With this system, all surgical objects are 3D models reconstructed from in vivo data. It is difficult at present to perform the calculations for organ structure with the anatomical structure compiled for the finite element method in real time. We have proposed the sphere-filled model to produce an elastic organ model. The model consist of a mass of small spheres filling a 3D organ model reconstructed from contour organ sets obtained from CT or MRI 3D data sets. All element spheres have the same radius and are placed in a face-centered cubic lattice. Finally, the surface model filled with spheres is constructed. The external force applied to the organ model displaces some of these spheres, and they in turn displace the spheres surrounding them, until ultimately the shape of the entire organ is deformed according to the magnitude and direction of the external force. The magnitude and direction of the force generated when the spheres are moved determines their return to their original position, allowing the force-feedback system to generate a sense of touch.

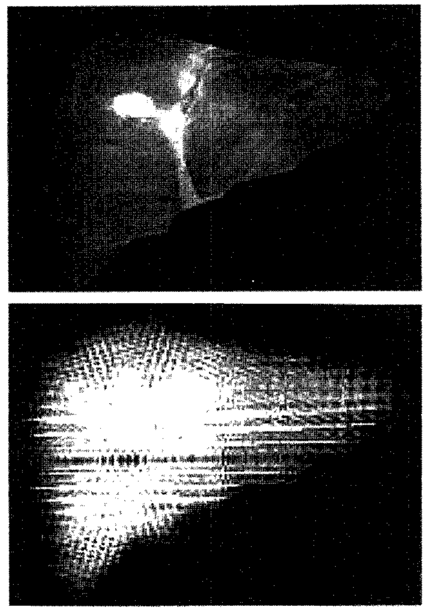
2-2. Force feedback device

In addition, a haptic device, which gives the operator a sense of touch as though actual contact were being made with the object, has been developed, and its practical effect in the realm of virtual reality was confirmed very recently. The force feedback device possesses a 16 degrees-of-freedom (DOF) force feeds back device for manual interaction with virtual environments. The features of the device manufactured for our virtual surgery system can be summarized as follows. (1) The force feedback system is composed of two types of manipulators, a force control manipulator and a motion control manipulator. (2) Three force control manipulators are attached to the end of the motion control manipulator. (3) Both ends of each force control manipulator are attached to the thumb, forefinger, and middle finger of the operator. (4) The force control manipulator has a joint structure with minimal inertia and less friction. (5) The motion control manipulator has mechanical stiffness.

3. Results

Using the liver as an example, the structure of our deformable organ model is shown in Fig.1a and b. Fig.1a is the reconstructed sphere-filled model of the liver. The liver contours are obtained from the 3D MRI data set with a 4 mm slice in a 4 mm pitch, and 18800 spheres fill this liver model. The surface of the liver model has been wrapped with surface images of autopsied liver tissue by using a texture mapping method to obtain a realistic appearance for the simulation. Fig.1b shows the spheres that fill the liver. Fig.2 shows the response of the deformable liver model to variations in force. Fig.2a-1 to a-3 show the performance of the model when pushed by a finger or a surgical tool. The white ball indicates the object that pushed the surface of the model liver. Fig.2b-1 to b-3 show the performance of the model when it was pinched by a surgeon's finger. These images were displayed at 10-12 frames/s in both cases, and there was no significant delay in image generation. Fig.3 shows the appearance of the force feedback system. A surgeon has attached his right arm to the device. The operator's thumb, forefinger, and middle finger are attached to the distal part of the motion controlled manipulators.

The rate of image generation is about 10 fold slower than the responsiveness of the force feedback device. We had to interpolate the magnitude of force when it was supplied to the force feedback device in order to create a realistic sense of touch. This speed did not change whether the operator touched the organ model with one finger or three fingers. One of the benefits of the sphere-filled model is that there is no difference in calculation time regardless of the number of outer forces. Fig.4 shows a simulation of open surgery in the abdominal region. Forceps, abdominal retractor, and surgical knife are used in this simulation. Data from the patient were reconstructed from the MRI data set, and the skin and organ surfaces were texture mapped (skin surface, patient's surface image; liver and intestines, image of autopsy specimen) to increase the sense of reality in the virtual environment. When the viewpoint, field of vision, and surgical tools are changed, laparoscopic surgery can be performed.



(a)

(b)

Fig.1. Structure of the deformable organ model in case of a liver. Fig.1a is the reconstructed liver model from the 3D data set of MRI. Fig.1b is inner struture of the reconstructed liver model.

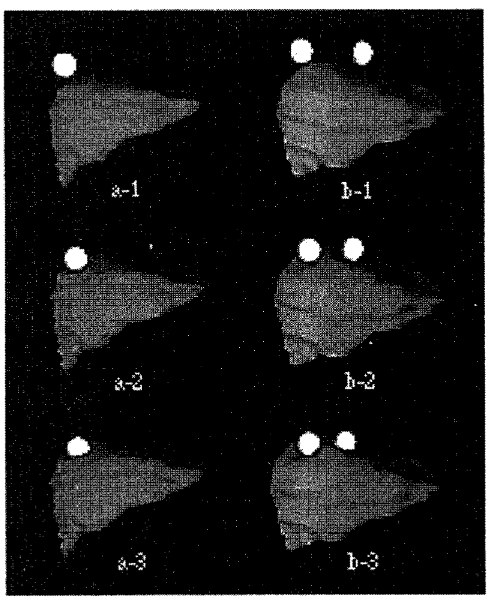


Fig.2. The response of the deformable liver model to variations in force.

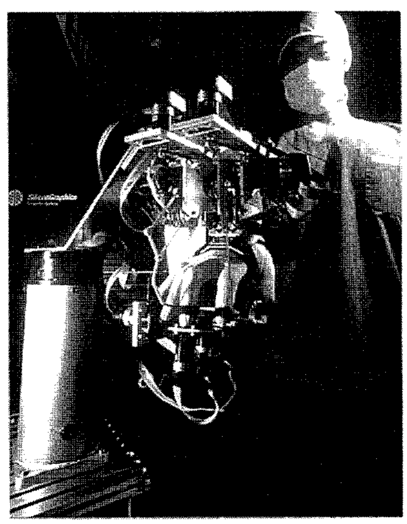


Fig.3. The appearance of the force feedback system .The operator's thumb, forefinger and middle finger are attached to the distal part of the motion controlled manipulators.

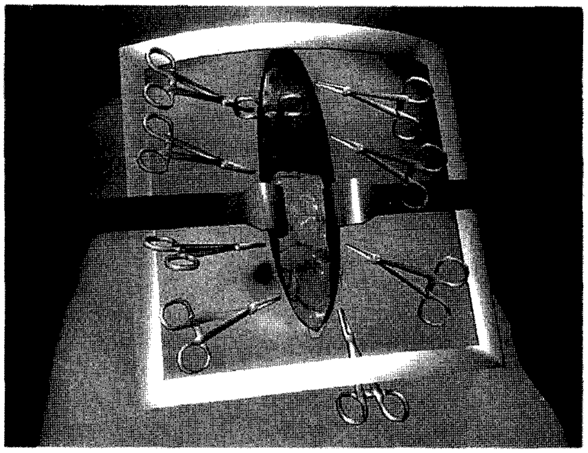


Fig.4. A simulation of open surgery in the abdominal region. Forceps, abdominal retractor and surgical knife are used in the simulation.

4. Conclusion

This method is suitable for real-time simulation and quantitative deformation of tissues. With our virtual surgery system equipped with a force feedback device, it is possible to perform surgical maneuvers with a sense of touch at a speed approaching that of the actual procedure. We have applied this system to surgery in the abdominal region in this paper, and we plan to extend the region of application to other organs and various types of surgery. In the near future, this surgical experience, in which a patient's morphological characteristics are reproduced in a virtual environment, will allow the establishment of a new method of clinically applicable surgery as well as educational innovations.

References

[1] Suzuki N, Takatsu A, Kita K, Tanaka T, Inaba R, Fukui K. "Development of an 3D image simulation system for organ and soft tissue operations." Abstract of the World Congress on Medical Physics and Biomedical Engineering 1994; 39a: 609.

[2] Suzuki N. "Planning system and support system for surgery using virtual reality." Proceeding of the First International Symposium on Computer Aided Surgery 1994;20-21.

[3] Suzuki, N., Hattori, A., Takatsu, A. "Medical virtual reality system for surgical planning and surgical support.", J. Comput. Aided Surg., 54-59, 1(2), 1995

[4] Suzuki, N., Kawakami, K., Hattori, A., Takatsu, A. "Abdominal surgery planning using medical virtual reality system.", CAR '96 1996; 1058