ICAT '99

Experiment of Tele-virtual surgery between Germany and Japan

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Key words: tele-surgery, virtual surgery, surgical simulation, tele-medicine, tele-existence

Abstract

Surgeons in Japan and Germany examined a hepatectomy simulation system as part of an application of tele-virtual surgery and a force feedback device. Using our system, surgeons in each country were able to perform various surgical maneuvers upon the same patient. Surgeons palpated abdominal skin, made electrical scalpel incisions and widened the incision line by using surgical tools in virtual space. The force feedback device conveyed tactile sensations to the user, while surgeons performed a virtual operation. Two graphic workstations of equal capability and force feedback devices were employed in each location. As each workstation communicated only event signals through an ISDN (64Kb) line, it was possible to obtain real time tele-virtual surgery without a large capacity communication infrastructure.

1. Preface

Three dimensional images reconstructed from MRI or CT images are currently used in various applications. The application of virtual reality (VR) techniques to 3D images has a large potential to provide future medical treatments through tele-diagnosis and tele-medicine.

In this paper, we report the results of a tele-virtual surgery experiment between Japan and Germany. Apparatus at both sites were connected by an ISDN line and equipped with a VR surgery system which had a force feedback function. Using this system, surgeons in each location shared identical tactile sensations.

2. Surgical simulation system

A surgical simulation system has a the useful application in the medical field. The system allows a user to repeatedly perform virtual surgery until a suitable procedure is established. This is especially useful for educational medical training.

We have been developing a virtual surgical simulation system upon the following requirements:

1). The system should enable the user to design and determine surgical procedures based on 3D model reconstructed from the patient's data.

2). By using force feedback device, the system must transmit authentic tactile sensations to the user during organ manipulations.

In our system, the surgeon (user) is able to perform various surgical maneuvers with suitable surgical tools as interactive actions in a virtual space. This system allows the

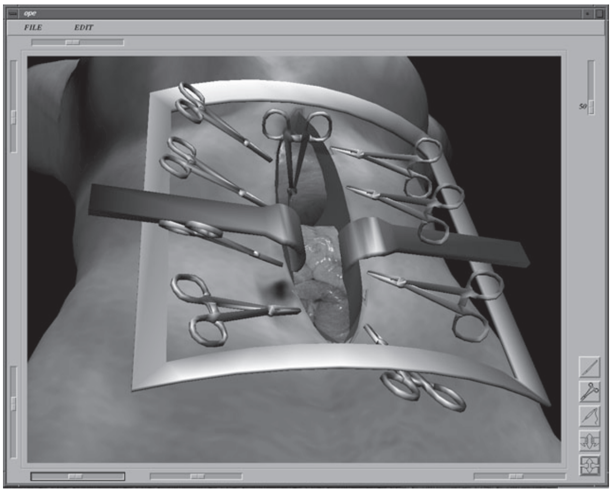


Fig.1 Application of surgical simulation used in this experiment

surgeon to make a scalpel incision, widen the incision line and secure it with forceps (Fig.1). All surgical procedures on a 3D object in a virtual space is proceed in real-time. Also 3D human structures are reconstructed from 3D patient data that gives such anatomical characteristics as vascularity. Numerical parameters such as location, depth, direction to the targeted organ and excised tissue volumes are measurable with quantitative accuracy.

The basic system function displays various viewpoints, scale and angles. It can also alter the transparency of an organ's multiple layers. Rendering by wire frames is also possible. In addition, each organ model is shaded by light sources set in the system's space and separated by easily distinguishable colors. In order to determine possible incision points, these models are texture mapped by using images of the patient's skin and extracted organ texture.

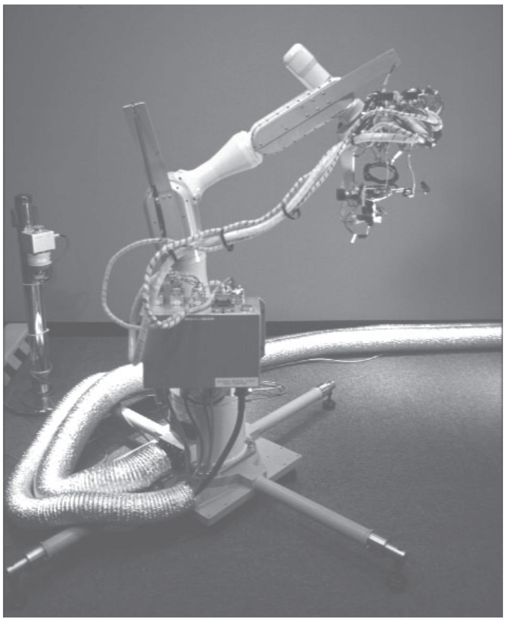


Fig.2 A view of the force feedback device

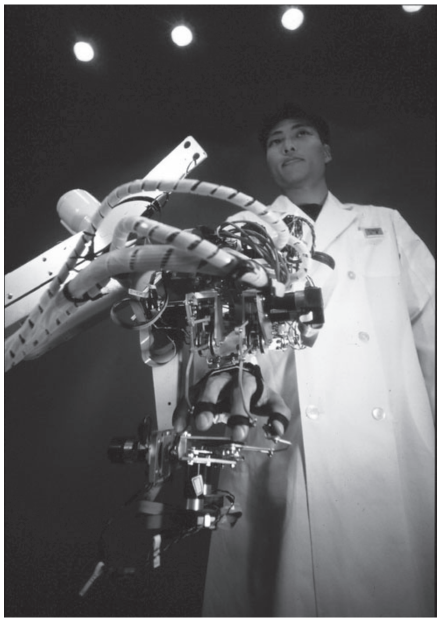


Fig.3 Force feedback device attached to fingers of the right hand

3. Force feedback device

A haptic device, which gives the operator authentic tactile sensations was confirmed very recently. We also have been developing a force feedback device which possesses 16 degrees-of-freedom (DOF) for manual interactions 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.

The device for the right hand is shown in Fig.2. The three force control manipulators are mounted at the pointed end of this device. These manipulators are attached to user's thumb, forefinger, and middle finger respectively. Fig.3

Fig.4 User with the force feedback device attached to both hands

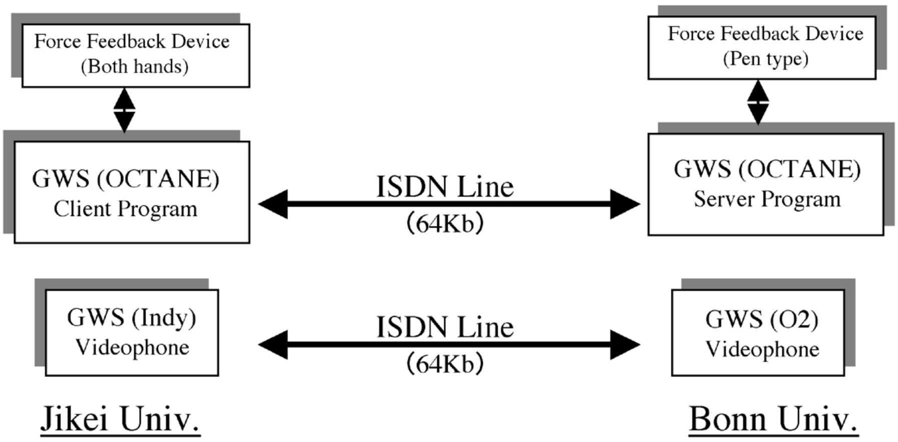
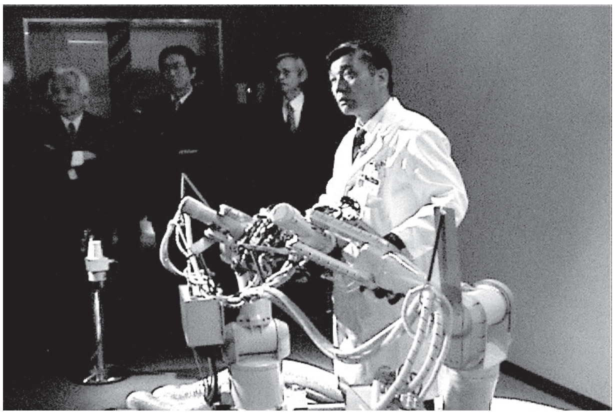


Fig.5 System outline of tele-virtual surgery system

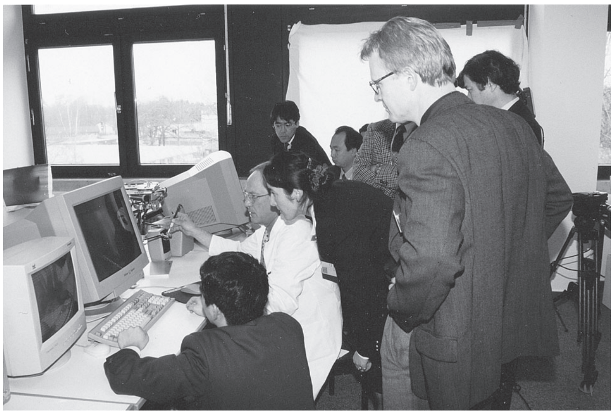
illustrates the user's fingers are attached to the manipulators. Fig.4 shows a user and the devices attached to both hands. These left and right force feedback devices have the same internal structure. The force feedback device for the right hand is a mirror image of the left one. These devices communicate data (finger location etc.) with the surgical simulation system through a LAN. When an interaction occurs between the user's fingers and a 3D object in a virtual space, a force parameter of tactile sensations calculated by the surgical simulation system, is transferred to these devices. This allows the user to experience tactile sensations in each finger.

4. Tele-surgical simulation system

In this experiment, we used a 1ch ISDN line (64Kb/s), because we intended to examine tele-virtual surgery without a large capacity communication infrastructure. However, it was difficult to transfer images of simulation results to each location in real-time. Therefore, we installed a simulation program and the patient's 3D modeling into



a. Japanese site



b. German site

Fig.6 Scene of the experiment at both sites

each system. The MRI images produced 3D data of the skin surface, liver, liver vessels, liver tumor and colon. The system transmitted and received only event signals related to the simulation. The event signal included force feedback device location data, the application's GUI event (buttons, sliders etc.) and calculated force of the force feedback device. The size of data per event is about 200 bytes. In this way, both sites were able to observe an identical simulation result in real-time.
The system's outline is shown in Fig.5. Participants at each location employed two graphic workstations (Japan site: Octane, Indy, German site: Octane, O2. All workstations are SGI inc. products) for the surgical simulation and teleconference. The workstations were connected by an ISDN line via an ISDN router. Each workstation had a force feedback device. In Japan, the force feedback was a glove type device attached to both hands, while a pen type device was used in Germany. These devices conveyed tactile sensations to the surgeons during the virtual surgical operation.
For communicating between each site, we used a teleconference application InPerson (SGI inc.) and video image and audio functioning at 300x200 pixels. This application's video frame was about 0.5 frame/sec.
When using network communication as in this experiment, we have to consider the data transfer delay. As this system doesn't manage event time, the delay causes a different result between two sites. We measured the delay between Japan and Germany by using UNIX command ping. Ping command result was 300ms (round-trip time). At this speed, the user need not wait for the processing completion However, if both users in each site interact with a 3D object simultaneously, each site's simulation result will be different. Therefore, each user conducted their procedures in turns.

5. Results

A simulated hepatectomy was chosen for the experiment. A scene of the experiment at the both sites is shown in Fig.6. Surgeons in each location palpated the patient's abdominal skin (Fig.7a) and discussed an incision position while observing the tumor location and vascularity of the liver by changing skin and liver surface transparency. In Germany, surgeons made an incision on the skin surface (Fig.7b) while a Japanese surgeon widened the incision line using a surgical tool. After widening, they palpated the exposed liver and deliberated upon an incision to the liver (Fig.7c). Finally, a German surgeon made an incision to the liver to complete the hepatectomy (Fig.7d).
In this system, the display's frame rate was 6-7 frame/sec. However, considering the surgeons action in surgical simulation, the frame rate was acceptable for the simulation. The two surgeon in Japan and Germany also had no comment on the frame rate.
Both surgeons evaluated this system and the experiment. The Japanese surgeon commented that he felt in close proximity the German surgeon and didn't sense any delay in the operation. The German surgeon observed that he could discuss surgery procedures in detail with the Japanese surgeon in order to find a solution to the surgical problem.

6. Discussion

We conducted an experiment in which two surgeons simulated virtual surgery while sharing identical tactile sensations over a long distance. It was possible to obtain realtime tele-virtual surgery without a large capacity commu-

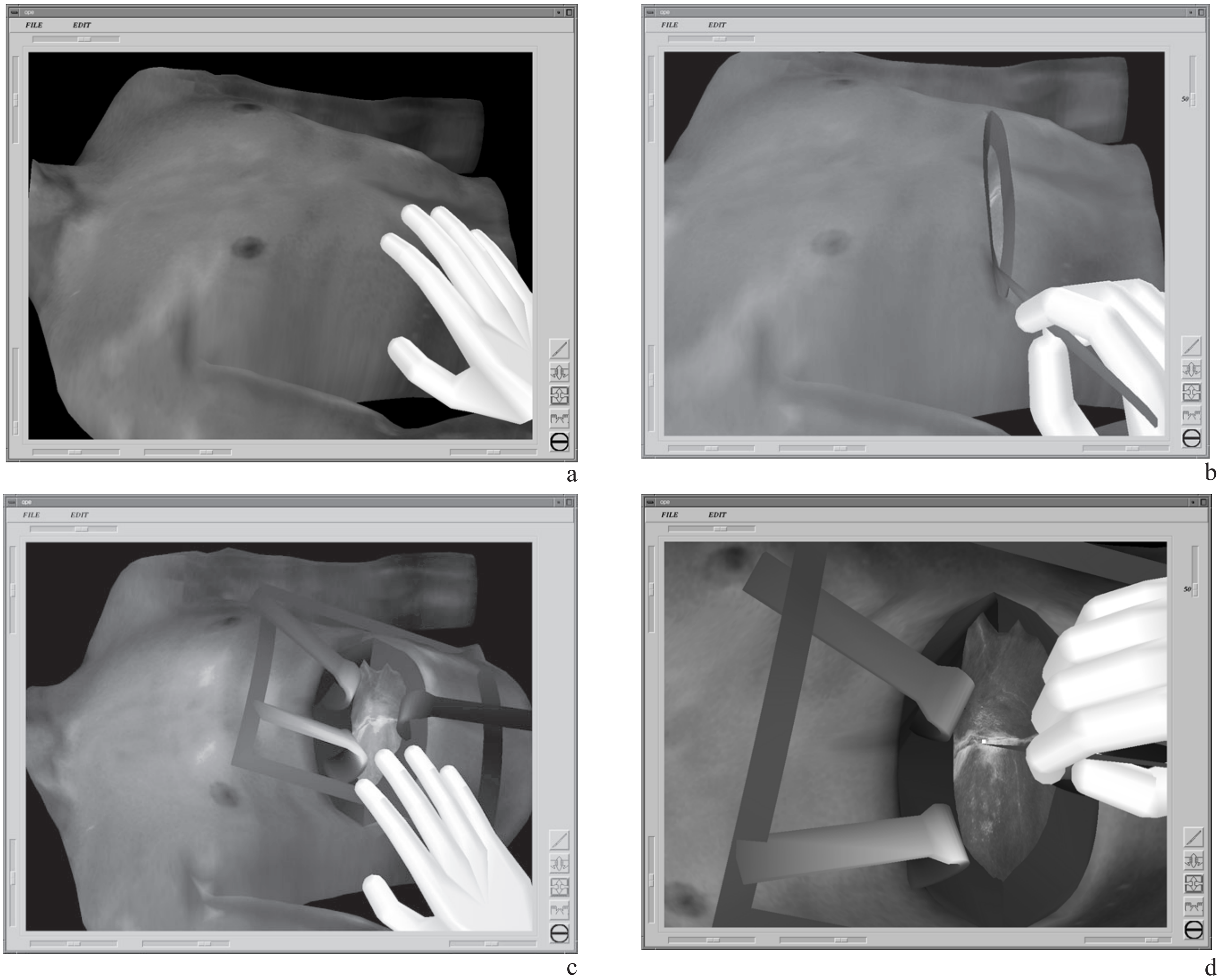


Fig.7 Images of hepatectomy simulation

a) palpating the abdominal skin, b) making an incision to the abdominal skin,

c) palpating the exposed liver, d) making an incision to the liver

nication infrastructure.

However, this system has a limitation. Both sites operated on a 3D object in turn, due to time delays when communicating event signals. The delay causes different results between two sites. Therefore, we need to evaluate the effects of time delay on the surgical simulation and develop a system which enable users to manipulate a 3D object simultaneously. If possible, the revised system will be the basis of the tele-surgery system.

The drawbacks of the force feedback function were caused by a 3D model structure. This model's elasticity is configured only on the surface, and doesn't depend on an organ's internal structure. Now, we are developing another 3D model "Sphere filled model". This model is reconstructed as a surface model filled with small element spheres with which a force acting on the internal structure can be calculated. By applying this model, tactile sensations will improve.

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