Virtual Reality as Human Interface and its application to Medical Ultrasonic diagnosis

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Invited Paper

ABSTRACT

Virtual reality is one of the intuitive man-machine interfaces, which uses human five senses. Virtual reality has many possibilities to enable medical doctor to understand diagnostic information intuitively and to do surgical operation more easily. In this paper, first of all, "What is Virtual Reality?" is introduced. After that, VR is applied to medical ultrasonic diagnosis to settle two problems, which are for ultrasonographer to lose orientation of tissue displayed in a monitor and to want to touch directly ultrasonic elastography image, respectively. VR technique can realize "Virtual See Through System" and "Virtual Palpation System". Virtual See Through System means that a picture is displayed on the diseased part, its original position. In Virtual Palpation System, a typical haptic display, PHANToM^{TM} is used. In this system, ultrasonographer or medical doctor can feel not only tumor's stiffness but its depth. The sense is so close to real human body touch. A new haptic rendering technique is proposed for it. Virtual Reality can provide an intuitive human interface for medical ultrasonic diagnosis system.

Keywords: Human interface; Virtual reality; Haptic device; Virtual palpation; Medical simulation; Computer assisted diagnosis

1. INTRODUCTION

Do you know novel game equipment, Wii^{TM}produced by Nintendo? I would like to remind you about its interface. It is not a conventional game controller. Player's movement is directly input to a game. The activity is used as human interface between man and machine. The intuitive interface is one of "Virtual Reality (VR)", which is five sense interface. It is not future technology now.

In this paper, first of all, "What is Virtual Reality?" is introduced. After that, VR is applied to medical ultrasonic diagnosis to settle two problems, which are for ultrasonographer to lose orientation of tissue displayed in a monitor and to want to touch directly ultrasonic elastography image, respectively. VR technique can realize "Virtual See Through System" and "Virtual Palpation System".

In recent years, Virtual Reality technique is applied to medical field, especially, virtual surgery simulator [1][2]. Unfortunately, however, appropriate expressions of haptic sense and real time registration are very difficult and have not been realized yet.

Virtual See Through System means that a picture is displayed on the diseased part, its original position in real time. In this system, positions of eye and an ultrasonic probe are measured by position sensors and an ultrasonic image which is a view in the case where ultrasonographer see the diseased part is reconstructed by using the position information in real time. The image is displayed on a micro display which is seated in front of eye.

In Virtual Palpation System, a typical haptic display, PHANToMTM is used. Ultrasonic elasticity imaging is one of the most important tissue characterization researches recently. HITACHI Medical Corporation has already produced the technique on a commercial basis and the equipment is mainly used for detection of tumor of breast cancer [3]. The newest equipment enables to display elasticity image in real time. As the technology advances, medical doctors and ultrasonographers are expecting to display the elasticity information as not only a visual image on 2D monitor but "the touch sense". That is to say, they expect virtual palpation system. In proposed system, ultrasonographer or medical doctor can feel not only tumor's stiffness but its depth. The sense is so close to real human body touch. A new haptic rendering technique is proposed for it. A target region is expressed by many small cubes in virtual space. Each of cubes has own elasticity information and we can feel haptic sense from pressed point, which is caused by elasticity of some cubes around pressed point. This newly-devised system enables to put the haptic sense to close "Human Haptic".

Virtual Reality can present an intuitive human interface for medical ultrasonic diagnosis system.

2. WHAT IS VIRTUAL REALITY?

A. Progress of computer and VR

In 1980s, computer had RAM in K byte order

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and processed character information only. Its man-machine interface was keyboard only. In 1990s, the order of RAM was increased in M byte order and the computer had been able to process image information by keyboard and mouse as human interface. Now, almost all the computers have G byte order RAM and can process movie information. What's next after 2000s? It is estimated that we could deal with space information in T byte order RAM. At that time, what interfaces are appropriate for the computer? The best way for man to deal with space information is to do as we usually do in real space. It means ordinary behavior of person is used as interface to computer. It can be realized by Virtual Reality. Virtual Reality is five senses interface, which also includes position sensing system, small I/O device like wearable computer, etc.

VR has 3 important components. "Sensing system" is used to detect user's motion in real 3D space and to input to computer. "Simulation system" creates virtual space. The role is to calculate a motion of virtual objects under real-virtual matching environment using input data from sensing system. The last one is "Display system". Display system outputs the calculation results of simulation system. This system is not limited to visual system. Aural, tactile and olfactory displays are required as the need arises. The relationship is shown in Fig.1.

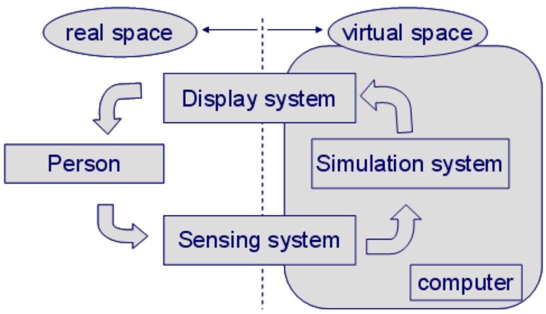

Fig.1: *The relationship among 3 components.*

B. Mixed Reality

Virtual Reality is a technique where person completely immerse in virtual space which consists of virtual information only, whereas Mixed Reality is a technique to merge virtual space and real space. Mixed Reality consists of 2 techniques. One is Augmented Reality, where real space is augmented by virtual information. The other is Augmented Virtuality, where virtual space is augmented by real space information. Especially, Augmented Reality is widely applied to various fields, for example, amusement, education, training, and of course medical application.

In the near future, immersive display, tactile display, position sensor and motion capture, etc. will be able to been used as human interface instead of legacy of computer interface, for example, keyboard, mouse and ordinary display (Fig.2).

Fig.2: *VR and MR as Human Interface*

3. MEDICAL APPLICATION OF VIRTUAL REALITY

Medical application of Virtual Reality can be categorized into three types. These are "Assistance of diagnosis", "Assistance of treatment" and "Functional substitution system".

Assistance of diagnosis is application of Augmented Reality. The typical techniques are stereo display and registration by using see-through type head mounted display and positioning sensor.

Assistance of treatment is to support surgical operation by robot or simulation. Surgical robot enables medical doctor to perform more precise surgery. Surgical simulation is used for preparation, planning and previous experience of surgery and training for young doctor.

Functional substitution system means one of the techniques of bio-cybernetics. This system is mainly for physically handicapped person. Artificial eye, arm and leg, and brain-computer interface (BCI) are included in this system.

In medical application of Virtual Reality, the keywords for research are "real-time", "patient's own information" and "intuitive understanding".

4. VIRTUAL SEE THROUGH SYSTEM

A. Purpose of the system

Virtual See Through System is an assistance system of medical ultrasonic diagnosis. An ultrasonographer usually looks away from a patient when diagnosis because a display is on an ultrasonic diagnostic equipment. In addition, the image on that display is changed in real time by ultrasonographer's operation of ultrasonic probe. Therefore, an ultrasonographer sometimes cannot decide an orientation of a tissue, and lose track of tissues. Virtual See Through System enables ultrasonographer to see tissues' images at their original position like seeing through patient's body.

B. Required components

Three components are required according to the components of Virtual Reality which is mentioned in II.A. "See around type face mounted display (FMD)" is a display which enables to see real space environment and an ultrasonic image (virtual environment) simultaneously on the real environment which means a patient's body). Micro display from Micro Optical Inc. is used in this research as shown in Fig.3.

Fig.3: *Clip on type micro display. The specifications are VGA (640 ×480), 24bits color, refresh rate: 60Hz, view angle: 16[degree] in horizontal and weight: 40g.*

The environment where real and virtual information exist together can be constructed by simulation system. In this research, WorldToolKit from SENSE8 Inc, which is API for C language, is used as real time simulation system of virtual environment.

Sensing and control of positions of ultrasonic probe, head (eye) and ultrasonic image are achieved by magneto electric sensor and the simulation system. The sensor system is ISOTRAKII^{TM} shown in Fig.4.

Fig.4: *ISOTRAKII^{TM} from POLHEMUS Inc. The precision is 2.4[mm] in position and 0.75[degree] in angle. The area where the positions can be measured is hemisphere whose radius is 76[cm]. The data rate is 30[pts/s] in two receivers case.*

The control is as follows:

- An ultrasonic image is displayed only when ultrasonic probe is on a patient's body and on the line of sight.
- The image is disappeared when looking away from the probe.
- The image is disappeared when the probe is off the line of sight.

C. System Configuration

System configuration is shown in Fig.5. The positioning sensors are set to the ultrasonic probe and FMD respectively. When ultrasonographer looks at diseased part on patient's body which is the position of ultrasonic probe, ultrasonographer can see an ultrasonic image in FMD. The view is like seeing through the body. Ultrasonographer can understand the image intuitively.

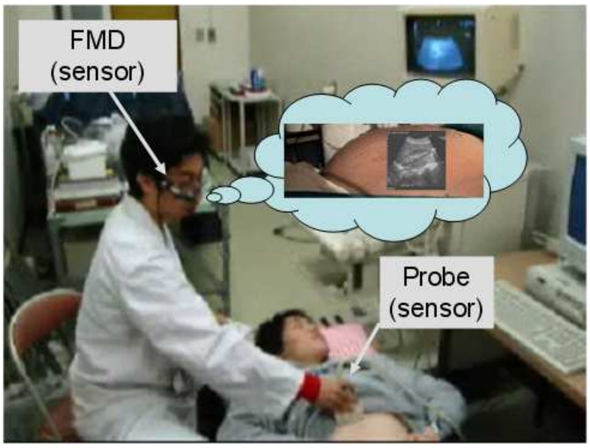

Fig.5: *The system configuration of Virtual See Through System*

5. VIRTUAL PALPATION SYSTEM

A. Purpose of the system

Tissue characterization is one of the most important researches in medical ultrasonic field. In this field, Hitachi medical corporation has developed real-time tissue elastography. This system can show hard tissue in blue and soft tissue in red. Although this system can show the stiffness information and it is so useful information for diagnosis, it is shown as visible information. Since the information is haptic information, it is expected to be touched directly by the sense of haptics. Virtual Palpation System enables medical doctor to get a sense of touch of tissue even if it is deep seated tumor. This system is provided as man-machine interface between medical doctor and real-time tissue elastography.

B. Rendering of elasticity information

Although 3D elasticity information can be measured by ultrasonic elasticity imaging, a medical doctor usually touches 2D surface of a diseased part, for example, a surface of skin in real palpation. Therefore, a rendering method in which 2D elasticity information distribution on the surface can be calculated from 3D elasticity information is needed for Virtual Palpation System. The rendering method also has to express the difference of rendered elasticity corresponding to the depth of a tumor in the diseased part. The deeper region the tumor is seated in, the lower the elasticity of the tumor influences the elasticity of the surface. The haptic sense also depends on the depth of press. In this paper, volume rendering technique in Computer Graphics is applied to haptic rendering. It enables to reproduce the human haptic sense of real palpation approximately and easily in real time without high computational cost technique, for example, finite element method. Of course, finite element method[4], etc may be needed for ideal and precisely accurate virtual palpation system. However, they take high computational cost and cannot provide real time system. In proposed method, real time system can be provided and it enables to reproduce real haptic sense approximately by setting appropriate weight coefficient in (1). The coefficients are decided from phantom experiments.

Fig.6 explains the rendering method.

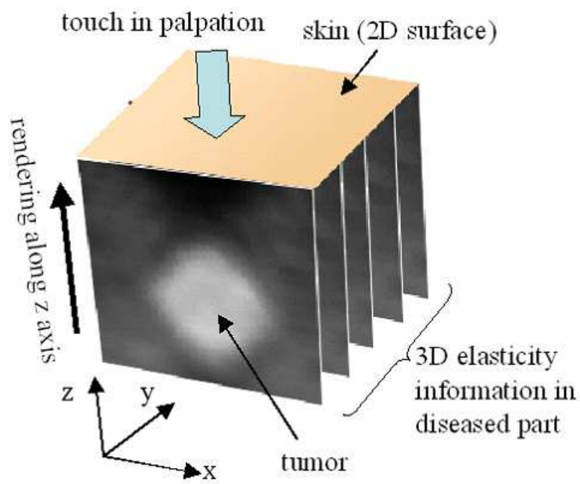

Fig.6: *Rendering of 3D elasticity information to 2D surface.*

$$f_s(x_s, y_s, x_d) = \sum_{x,y,z} w(|x - x_s|, |y - y_s|, z, x_d) \cdot f_v(x, y, z) \quad (1)$$

$f_s(x_s, y_s, x_d)$ is reproduced elasticity on the 2D surface at pressing point (x_s, y_s) when the point is pressed to x_d in depth. $f_v(x, y, z)$ is the 3D elasticity information which is measured by elastography. $w(x, y, z, x_d)$ is weight coefficients distribution. The shallower the depth is, the larger the coefficient is. That is to say, a shallow seated malignant tumor, whose elasticity is usually higher than benign one, can be felt well on the surface by sense of touch. The weight coefficient is determined by a medical doctor subjectively and empirically, and saved as the medical doctor's calibration data in advance to practical use.

C. Expression of resistance on 2D surface

A medical doctor often slides fingers on the surface of skin in real palpation. The horizontal movement of fingers on the surface is very important in real palpation. Unfortunately, however, such system has not been proposed yet [5]. The medical doctor feels resistance at edge of tumor as shown in Fig.7. The resistance is important information for diagnosis. Therefore the resistance also has to be reproduced in this Virtual Palpation System.

$f_s(x_s, y_s, x_d)$ is differentiated with respect to (x_s, y_s), which is the coordinates of position of a haptic device (as in fingers), every simulation loop in virtual space. If the result is larger, the resistance is set for larger value. The setting is determined empirically from the measured elasticity. The relationship between the result of differentiation and the resistance value, which is determined empirically and subjectively, is saved as one of the calibration data. This technique can enhance the edge of tumor and bring the sense of touch close to real sense.

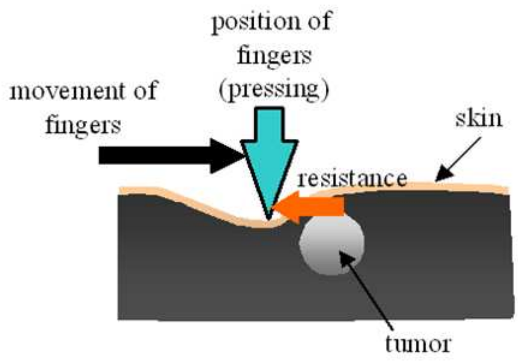

Fig.7: *Resistance on the surface in palpation.*

D. Haptic device and Development Environment

This system uses PHANToM Desktop^{TM} (SensAble Technologies Inc.) shown in Fig.8 as a haptic device. OpenGL is used as graphic library for construction of virtual space in the visual sense, and GHOST SDK is used as a software library (C++ Library) to control PHANToM Desktop^{TM} , and to realize force feed-back, haptic sense and simulation loop in virtual space.

The step for representation of haptic sense is as follows:

1. 3D elasticity information is measured by Ultrasonic elasticity imaging equipments.
2. 3D elasticity information is rendered to 2D surface by (1).
3. 2D elasticity distribution is presented to user in haptic sense by PHANToM Desktop^{TM} and GHOST which calculates the sense according to Spring-damper model.
4. The resistance on 2D surface is calculated by modified GHOST class.

E. Ultrasonic Elasticity Imaging

In this experiment, a result of gelatin phantom experiment of ultrasonic elasticity imaging is used. The phantom form is cube (80mm*80mm*60mm). The phantom includes a sphere whose elasticity is higher (50kPa) than surrounding one (10kPa). The diameter is 15mm. The elasticity distribution is obtained by a method shown in [1]. The phantom form and the obtained distribution are shown in Fig.9.

F. System construction

1) Rendering of elasticity information: The ob-

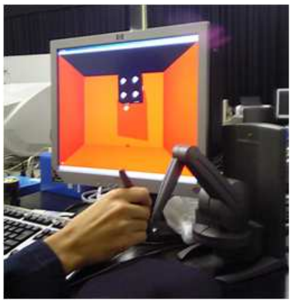

Fig.8: *PHANToM Desktop^{TM} (SensAble Technology Inc.)*

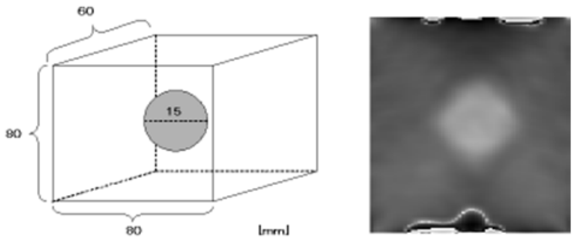

Fig.9: *Phantom form (left) and a slice of elasticity imaging (right, x-z plane (y=0)).)*

tained 3D elasticity information of the phantom is rendered to 2D screen by the method described in V.B. The reproduced elasticity on 2D surface depends not only on the 2D coordinates of the pressing point but on the depth of press. An example of the results is shown in Fig.10.

2) Representation of human haptics: 2D elasticity distribution is aligned with 2D rigid plane in virtual space as shown in Fig.10. Blue cursor in bottom right in Fig.10 is position of a haptic device, PHANToM Desktop^{TM}.

When the rigid plane is pressed perpendicularly to the plane by the haptic device, user can feel reaction force corresponding to the 2D elasticity distribution. Of course, the reaction force is reproduced depending on the depth of press. The reaction force is calculated

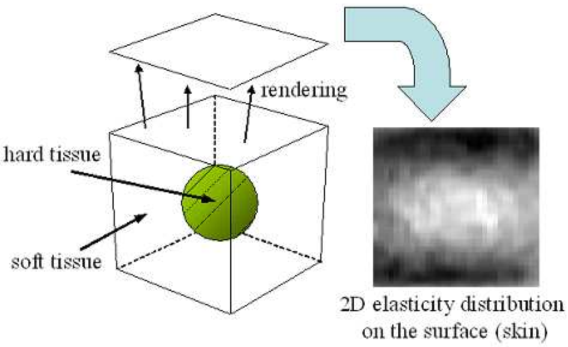

Fig.10: *Rendering of 3D elasticity information to 2D screen.*

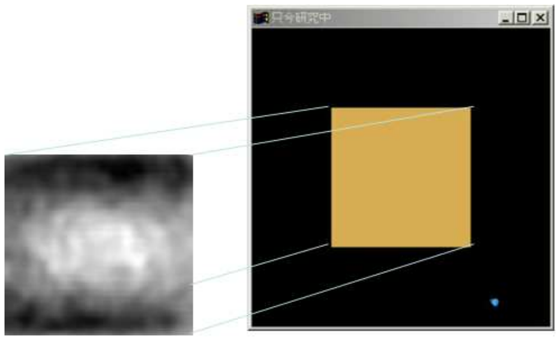

Fig.11: *Allocation of 2D elasticity distribution to virtual space.*

by GHOST SDK which uses Spring-damper model. The rigid plane moves to the pressing direction.

3) Expression of resistance on the 2D plane: When fingers (the haptic device) slide on the plane, the fingers (the haptic device) have to feel the resistance as described in V.C. The resistance depends on the horizontal movement of the haptic device and variation in elasticity on the plane. In this system, a class of GHOST SDK which is to write "viscosity resistance" which depends on a movement of a haptic device is modified and a new class is created to reproduce the resistance.

4) Constructed Virtual Palpation System: An action of constructed system is shown in Fig.12.

Fig.12: *An action of proposed Virtual Palpation System.*

G. What is more appropriate device?

Although PHANToM Desktop^{TM} is one of the most typical and popular haptic devices, it is stylus type display. In practical palpation, medical doctor doesn't use any equipment like stylus. Some fingers are used. Therefore, it is expected that medical doctor can touch a tissue and feel the sense of haptics of it by his / her own finger.

Author's group has produced a new haptic device using artificial muscle by way of trial. It is shown in Fig.13. The artificial muscle contracts quickly by rise of temperature when current flows into it. The contraction is used to fix a bend of finger. This system is put on Cyber Glove™[6].A user can behave naturally in virtual space since the system is smaller and lighter than Cyber Grasp™[6], which is a popular haptic device of finger type.

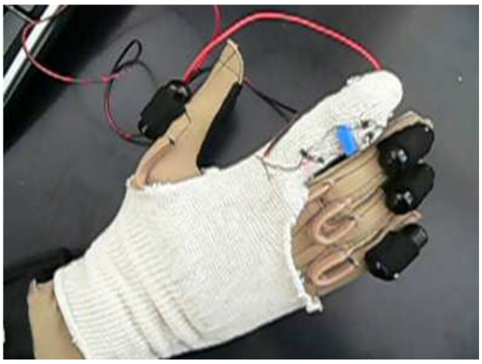

Fig.13: *Proto type of a new haptic device using artificial muscle.*

6. CONCLUSION

Virtual Reality is not dream technique now. A part of Virtual Reality has been already realized as five senses human interface.

Virtual Reality is also being applied to medical field, especially, for "Assistance of Diagnosis", "Assistance of Treatment (surgical operation)" and "Functional Substitution System". These applications enable user to understand diagnostic information intuitively.

This paper introduces "Virtual See Through System" and "Virtual Palpation System".

Virtual See Through System enables ultrasonographer to see tissues' images at their original position like seeing through patient's body. This system can solve a problem where ultrasonographer sometimes loses orientation of tissues.

Virtual Palpation System enables medical doctor to get a sense of touch of tissue without surgery even if it is deep seated tumor. This system is provided as man-machine interface between medical doctor and real-time tissue elastography. A new haptic rendering method and haptic device is proposed.

Virtual Reality can present an intuitive human interface for medical diagnosis, especially, ultrasonic diagnosis.

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