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Investigation on Virtual Palpation System using Ultrasonic Elasticity Imaging

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***Abstract*— In the field of medical ultrasound, ultrasonic elasticity imaging has been developed and used in practical diagnosis. However, unfortunately, elasticity information is now displayed on ordinary 2D screen (for example, CRT). Since elasticity information is haptic information, not visible information, the information is expected to be displayed in "the sense of haptic". In this research, it is attempted that elasticity information is displayed on haptic display for virtual palpation system. In this system, a surface of diseased part is expressed by one rigid plane which has elasticity information. The elasticity information is a function of 2D coordinates of a haptic device on the plane. 3D elasticity information of the diseased part which is measured by ultrasonic elasticity imaging equipment is rendered to the plane by a way which is similar to volume rendering technique, to reduce computational cost and to realize human haptic sense easily in virtual palpation in real time. It is also important to reproduce the haptic sense in the case where a physician slides fingers on the surface in real palpation. The proposed system enables to reproduce the haptic sense in not only the perpendicular direction to the surface but the direction of horizontal movement of fingers on the surface. This system can realize virtual palpation system.**

I. INTRODUCTION

ULTRASONIC imaging is widely applied and indispensable technique in medical field currently. Although it has many advantages compared with X-ray imaging technique, one of its weak points is that ultrasonic echo image is not quantitative. Therefore, there are many researches about quantitative image construction, which is called "Tissue Characterization".

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 [1]. 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 recent years, virtual reality technique is applied to medical field, especially, virtual surgery simulator [2][3]. Unfortunately, however, appropriate expression of haptic sense is very difficult and has not been realized yet though the expression is very important. There are two reasons in it. One is the difficulty of measurement of tissue's own elasticity. The surgery system which is mentioned above uses the statistical value, which is not a patient's own data. The other is that computational cost is very high for calculation of reaction force which appears on a surface of a diseased part. Because it has to be calculated from 3D elasticity information by, e.g., finite element method for strict accuracy of human haptic sense [4].

There is another problem in virtual palpation system. In real palpation, a physician slides fingers on the surface of skin. The haptic sense for a physician to feel in the horizontal movement on the surface is important for diagnosis. Therefore, virtual palpation system has to realize the haptic sense. Unfortunately, however, such system has not been proposed yet [5].

In this research, a realistic virtual palpation system is proposed. Although it may not be ideal one, it has feasibility to reproduce the haptic sense of real palpation in real time, easily and approximately. In that meaning, the system is realistic. To reduce computational cost and to realize human haptic sense easily in real time, volume rendering technique is applied to the virtual palpation system after getting 3D elasticity information by ultrasonic elasticity imaging. In addition, the proposed system enables to reproduce the haptic sense in not only the perpendicular direction to the surface of a diseased part but the direction of horizontal movement of fingers on the surface. This system can realize virtual palpation system. Furthermore, the system can present "direct touch" to a deep seated tumor virtually without surgical extraction of the tumor, and it can be used for real time tele-palpation system. The proposed virtual palpation system can provide an intuitive human interface to ultrasonic elasticity imaging.

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II. METHODS

A. Rendering of elasticity information

Although 3D elasticity information can be measured by ultrasonic elasticity imaging, a physician 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. 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, 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 enable to reproduce real haptic sense approximately by setting appropriate weight coefficient in (1).

Figure 1 explains the rendering method.

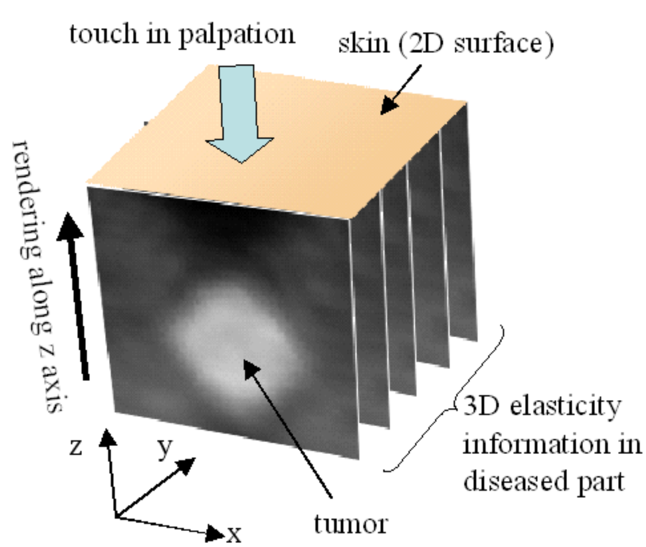

Fig.1. Rendering of 3D elasticity information to 2D surface.

3D elasticity information which is measured by ultrasonic elasticity imaging equipment is rendered to 2D surface, for example, skin, by (1).

$$f_s(x,y) = \sum_z w(z) \cdot f_v(x,y,z) \qquad (1)$$

$f_s(x,y)$ is 2D elasticity distribution on the 2D surface. $f_v(x,y,z)$ is the 3D elasticity information. $w(z)$ is weight coefficient which depends on depth (x coordinate). 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 physician subjectively and empirically, and saved as the physician's calibration data in advance to practical use.

B. Expression of resistance on 2D surface

A physician slides fingers on the surface of skin in real palpation. The horizontal movement of fingers on the surface is very important in real palpation. The physician feels resistance at edge of tumor as shown in Fig.2. The resistance is important information for diagnosis. Therefore the resistance also has to be reproduced in virtual palpation system.

$f_s(x,y)$ is differentiated with respect to (x, y), 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.

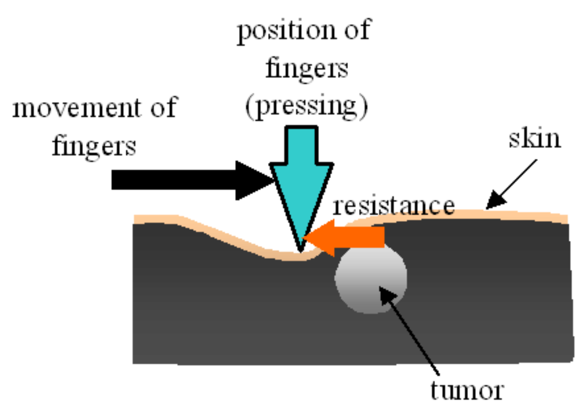

Fig.2. Resistance on the surface in palpation.

III. EXPERIMENT

A. Haptic device and Development Environment

This system uses PHANToM Desktop^{TM} (SensAble Technologies Inc.) shown in Fig.3 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. (see III B)

2) 3D elasticity information is rendered to 2D surface by

(1). In this experiment, $w(z)$ is set to 1. (see III C 1))

3) 2D elasticity distribution is presented to user in haptic sense by PHANToM Desktop™ and GHOST which calculates the sense according to Spring-damper model. (see III C 2))

4) The resistance on 2D surface is calculated by modified GHOST class. (see III C 3))

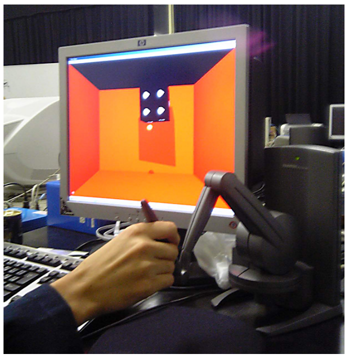

Fig.3. PHANToM Desktop™ (SensAble Technology Inc.)

B. 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.4.

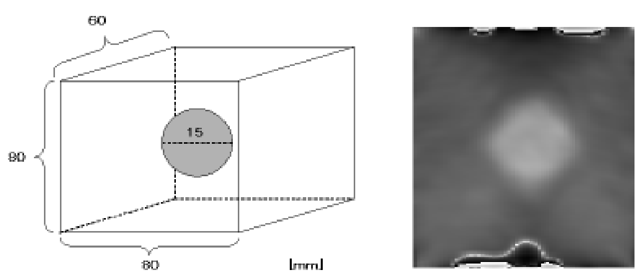

Fig.4. Phantom form (left) and a slice of elasticity imaging (right, x-z plane (y=0)).

C. System construction

1) Rendering of elasticity information: The obtained 3D elasticity information of the phantom is rendered to 2D screen by the method described in II.A. The result is shown in Fig.5. The reason why 2D rendered image does not give a circular elasticity distribution is due to low resolution of ultrasonic elasticity imaging equipment.

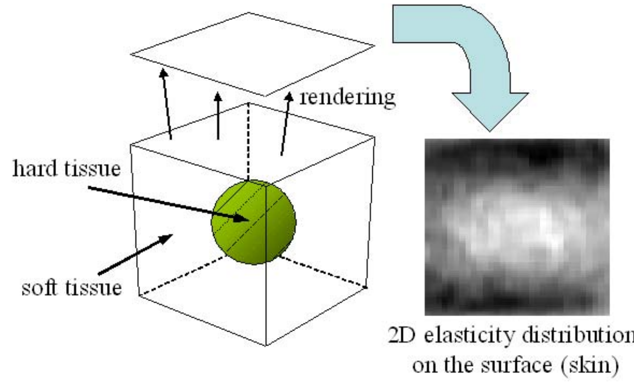

Fig.5. Rendering of 3D elasticity information to 2D screen.

2) Representation of human haptics: 2D elasticity distribution is aligned with 2D rigid plane in virtual space as shown in Fig.6. Blue cursor in bottom right in Fig.6 is position of a haptic device, PHANToM Desktop™.

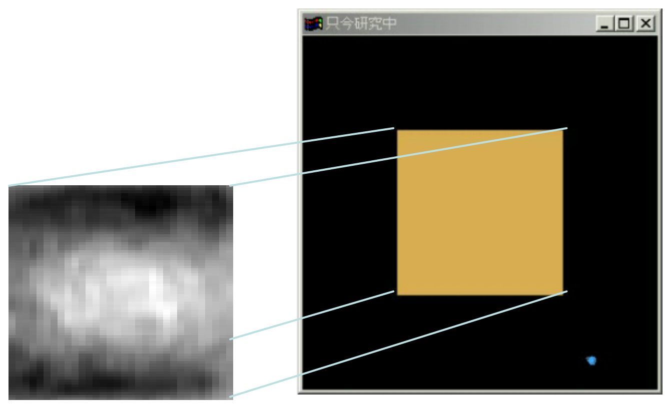

Fig.6. Allocation of 2D elasticity distribution to virtual space.

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. The reaction force is calculated by GHOST SDK which uses Spring-damper model. Of course, 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 II.B. 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.7.

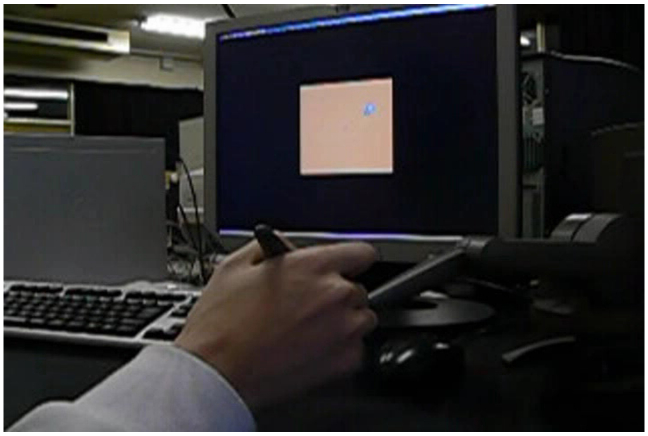

Fig.7. An action of proposed virtual palpation system.

IV. CONCLUSIONS

Recently, medical ultrasonic elasticity imaging technique has been developed. It is expected to realize "virtual palpation system" for accurate comprehension of the elasticity information by medical doctor and ultrasonographer.

In this research, typical haptic device, PHANToM Desktop^{TM} is applied to ultrasonic elasticity imaging to realize virtual palpation system. Furthermore, to accomplish real-time representation of Human Haptics, reduction of computational cost is attempted. In this proposal, 3D elasticity information of a diseased part is rendered to 2D rigid plane in virtual space. The rendering method is similar to volume rendering technique of Computer Graphics. A weight coefficient in the rendering process for each of 3D elasticity information is determined according to the depth subjectively and empirically by a physician and the coefficients are saved as calibration data for the physician. In addition to it, the proposed system can reproduce a resistance in the direction of horizontal movement of a haptic device on the surface of the plane when a user slides a haptic device on the surface since the resistance is very important information in real palpation. The resistance becomes larger at the edge of a tumor. The reaction force when the 2D rigid virtual plane is pressed perpendicularly and the resistance when a haptic device is slid on the plane are calculated by using GHOST SDK for software development for PHANToM Desktop^{TM}, which calculates a reaction force by using spring damper-model. A part of the SDK, a class in the C++ library regarding viscosity resistance is modified to realize the proposed condition, especially, the resistance in the direction of horizontal movement of a haptic device on the surface.

As the result, this system can realize virtual palpation system. Furthermore, the system can present "direct touch" to a deep seated tumor virtually without surgical extraction of the tumor, and it can be used for tele-palpation system. The proposed virtual palpation system can provide an intuitive human interface to ultrasonic elasticity imaging.

Future work is how put the human haptics close to real haptic sense quantitatively. It means how to produce calibration data for each of physicians. They may depend on not only z but x and y. And an application of this system to practical diagnostic system is also remained.

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