Haptic Rendering for Virtual Palpation System using Ultrasonic Elastography

Kazuhiko Hamamoto

ABSTRACT

"Virtual palpation system", which can present a tactile sense as user palpates a patient in virtual space based on the patient's elasticity information obtained by an ultrasonic elastography. This system uses haptic rendering. In this research, two haptic rendering methods are introduced, which are "cube method" and "3D projection method". Although cube method is more simple method, 3D projection method can realize more intuitive and effective virtual palpation system.

1. INTRODUCTION

Ultrasonic imaging is widely applied and indispensable technique in medical diagnostic field currently. It has many advantages compared with X-ray imaging, MRI and so on. Unfortunately, however, it has a serious weak point, where 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 to decide whether a tumor (for example, in breast) is benign or malignant [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 image as not only a visual image on 2D monitor but "the sense of touch". A human interface using the five senses like this are called "Virtual Reality". Using virtual reality enables a user to access the space which computer deals with by human sense and to use one's ordinary behaviour as an interface to computer. That is to say, that medical doctors and ultrasonographers are expecting is "virtual palpation system". Virtual Palpation System enables medical doctors and ultrasonographers to get the sense of touch of tissue even if it is deep seated tumor. This system is provided as man-machine interface between medical doctors/ultrasonographers and real-time tissue elastography.

In recent years, virtual reality technique is applied to medical field, especially, virtual surgery simulator [2][3]. And I have already introduced virtual reality application for medical ultrasonic diagnosis in ref[4]. In ref[4], virtual palpation system has been also introduced. The virtual palpation system uses PHANToM Desktop™, produced by Sensable Technologies Inc, which is the most popular haptic device. This device presents the sense of touch (reaction force) on a point in virtual space with the point's elasticity by Spring-Damper theory. That means a technique is strongly required which can calculate accurate elasticity on the pressed point considering surrounding three-dimensional elasticity information and the depth of the press. This process is called "haptic rendering". This rendering process is very important because human body is not homogeneous and has non-linear characteristic. Three-dimensional finite element method is usually used for the calculation to get strict accuracy of human haptic sense [5]. However, it takes high computational cost and cannot realize a real-time virtual palpation system.

2. CUBE METHOD

2.1 Basic concept

To express haptic sense and dent of human body in the virtual palpation:

1. A virtual human body is constructed by many
Fig. 1: Basic concept of Cube Method.

2. When a cube is pressed, not only the cube but some cubes around the cube are moved to the direction of the pressure.
3. When the pressure is disappeared, the cubes come back to their original positions.
4. The reaction force and the depth of dent are calculated based on the cubes’ mass which is decided according to the elasticity information of the cube.
5. How to assign the elasticity information to the cube and to decide the mass and the dent of the cube are determined subjectively and empirically.

Fig. 2: A Virtual body constructed from 75 cubes.

2.2 Simulation

Fig. 2 shows a virtual body model. This model is constructed from 75 cubes. Fig. 3 shows a dent of this body when its center cube are pressed. "PHANToM Desktop™", which is a famous haptic device is used in this simulation (Fig. 4). Not only the cube but some surrounding cubes are moved simultaneously along the pressing direction. A user also can feel mass of each cubes. If the mass is heavy, it becomes more difficult to move it. It can be felt as "modulus of elasticity".

Unfortunately, however, it sometimes takes a huge computational cost to calculate the movements of cubes. High resolution, that means so many small cubes, might cause an error where the body cannot keep the relationship of position among each cubes. It is a severe problem of this method.

2.3 3D Projection Method

2.4 Basic concept

This method calculates the haptic sense on skin surface which reflects 3D modulus of elasticity by a
The rendering process consists of 4 parts: which are "Normalization of modulus of elasticity for PHANToM", "Transformation of modulus of elasticity according to depth", "Displacement filter" and "Calculation of reaction force".

2.5 Normalization of Elastic Modulus for PHANToM

In this process, elastic modulus which is measured quantitatively is normalized for PHANToM. This process enables the elastic modulus to be able to be used in PHANToM Desktop™. A parameter used in this process is called "Elasticity Information Parameter (EIP)". This parameter is set by a user according to the real sense of touch. A user adjusts EIP as the virtual sense of touch becomes the same as the real sense of touch.

2.6 Transform of Elasticity for depth

Reaction force which is felt when a user presses a surface depends on the depth of the press. In addition, elasticity information which is seated closely to the surface affects the reaction force significantly and effect of elasticity information which is seated deeply to the reaction force is small. In this process, elasticity information is transformed according to the depth of the press by eqn. (1).

\[ E'_{(x, y, z)} = \frac{E(x, y, z)}{p^z} \]  

\( z \): the depth of the press  
\( E'(x, y, z) \): transformed elasticity at depth \( z \)  
\( E''_{(x, y, z)} \): elasticity at depth \( z \) after II B process

\( p \): depth parameter(\( DP \))  
\( DP \) is also set by a user in the same way as EIP.

2.7 Displacement Filter

The reaction force is affected by not only elasticity information along the direction of the press but the surrounding elasticity information of the pressed point. The effectiveness of the surrounding elasticity information is investigated by using a phantom made from vinyl chloride material whose elasticity is close to one of human body. Some thin strings are embedded in the rectangular prism phantom in a lattice shown in Fig. 6(a). The deformation of the strings is measured when the phantom is pressed shown in Fig. 6(b). The effectiveness is determined by the deformation experimentally. The estimated effectiveness is shown in Fig. 7. \( Z \) direction is the direction of the press, and the left end column of the top row is the position of the press. This effectiveness table is called "isplacement Filter (DF)".

\( DF \) consists of 2 filters. One is for \( x-z \) plane and the other is for \( y-z \) plane. That is to say, \( DF \) is expressed in \( DF(x, z) \) and \( DF(y, z) \). If the depth of the press is "4", 4 rows and 5 columns of \( DF \) are used. The accurate elasticity \( E'' \) on the pressed point considering surrounding three-dimensional elasticity information and the depth of the press for PHANToM Desktop™ is calculated in eqn. (2).

\[ E''_{(x, z)} = \sum_{|x|=0}^{4} \sum_{|y|=1}^{4} \sum_{z=0}^{d} (E'(x, z) \cdot DF(x, z)) + E'(y, z) \cdot \sum_{z=0}^{d} DF(y, z)) \]  

\( E''_{(x, z)} \): elasticity at the position of the press for PHANToM Desktop™

2.8 Calculation of the reaction force

Finally, the reaction force \( F \) presented by PHANToM Desktop™ is calculated in eqn. (3).

\[ F = f(E'') \times d \]  

\( f(E'') \) is the spring constant.

This haptic rendering method by 3D projection method can produce the accurate touch of the sense
approximately by controlling parameters, \(EIP\) and \(DP\) in real time as shown in Fig. 8.

### 2.9 Visible Rendering

Visible rendering is also important for 3D projection method. First idea is shown in Fig. 9 (left). In this method, virtual skin can be pressed along only perpendicular direction to display. And the virtual skin is not dented and moved along the direction as 2D plane. The current idea is shown in Fig. 9 (right). The dent of virtual skin is expressed by \(NURBS\). It can realize more intuitive and realistic expression of the dent of skin.

### 3. CONCLUSION

The haptic rendering methods for virtual palpation system have been proposed. The system uses elasticity information measured by ultrasonic elastography and can present the virtual sense of touch which is the same as the real sense of touch in practical palpation. In this paper, two new haptic rendering methods are proposed for the virtual palpation system. The cube method is the most simple rendering method, but it takes high computational cost in the case of high resolution, that means a huge number of cubes. The 3D projection method enables to realize re-producing elasticity of the point of press for PHANToM Desktop\textsuperscript{TM} in real-time with considering the depth of press and effect of three dimensional distribution of elasticity information. In this method, two parameters setting are needed, \(EIP\) and \(DP\). The proposed haptic rendering method can be realized by fixed \(DP\) and setting \(EIP\) only from elasticity information measured by ultrasonic elastography without dependence on user. There is remained evaluation of the proposed system by medical doctor in the future.

### References


Kazuhiko HAMAMOTO, was born in Nagasaki prefecture, Japan in 1966. He received B.D, M.D and Ph.D from Tokyo University of Agriculture and Technology in 1989, 1991 and 1994 respectively. He was assistant professor in Dept. of Communications Eng., Tokai University in 1994, Associate Professor in 1999, and Professor in Dept. of Information Media Technology, School of Information and Tele-communication Eng., Tokai University in 2009 and now. His research interest is information architecture, especially, medical image processing, human interface and virtual reality. He joins IEICE, IEEJ, IEEE, VRSJ, JSST, etc. He is a committee member of Technical Committee of Medical and Biological Engineering, Society of Electronics, Information and Systems, IEEJ and on the board of trustees of JSST.