Development of Virtual Palpation System using Ultrasonic Elastography

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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 is proposed. This system uses 3-dimentional haptic rendering technique. In this research, it is attempted to determine parameters which are used to realize the same tactile sense as one in actual palpation. The parameters are determined experimentally using some breast phantom.

Keywords: Virtual reality; Palpation; Elastography; Ultrasonic imaging; Haptic rendering

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 information as not only a visual image on 2D monitor but "the sense of touch". That is to say, they expect "virtual palpation system". Virtual Palpation System enables medical doctor 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 doctor 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^{TM}, 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.

In this research, volume rendering technique in Computer Graphics has been applied to haptic rendering [6][7]. It enables to reproduce the human haptic sense of real palpation approximately and easily in real time without high computational cost. 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 this proposed method, real time system can be provided and it enables to reproduce real haptic sense approximately by setting some appropriate parameters. The parameters are decided from phantom experiments.

In this paper, the setting of parameters is investigated. Four phantoms which have different elasticity are made from vinyl chloride material or polyurethane material. The parameters are set as the sense of touch in virtual space becomes the same as the sense of touch of the phantom. Whether the parameters are unique for the virtual palpation system or depend on users' characteristics are investigated. If the parameters depend on users' characteristics, calibration process for each user might be needed. Such problem for practical use is also investigated.

2. PROPOSED HAPTIC RENDERING

2.1 Transform of Elasticity for PHANToM

In this process, elasticity information which is measured quantitatively is transformed. This pro-

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cess enables the elasticity information to be used in PHANToM DeskTop^{TM}. 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.

2.2 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).

$$E'(x, y, d) = \frac{E(x, y, d)}{p^d} \tag{1}$$

d : *the depth of the press*
$E'(x, y, d)$: *transformed elasticity at depth d*
$E(x, y, d)$: *elasticity at depth d after II(A) process*
p : *depth parameter (DP)*

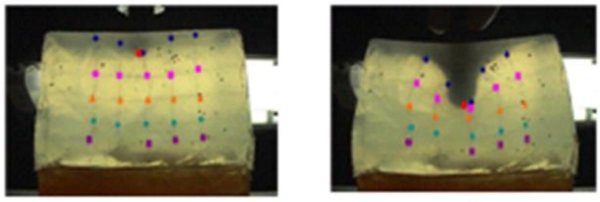
DP is also set by a user in the same way as EIP.

2.3 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.1(a). The deformation of the strings is measured when the phantom is pressed shown in Fig1(b). The effectiveness is determined by the deformation experimentally. The estimated effectiveness is shown in Fig.2. 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 “Displacement 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^{TM} is calculated in eqn.(2).

$$E'' = \sum_{|x|=0}^{4} \sum_{|y|=1}^{4} \sum_{z=0}^{d} \{E'(x, z) \bullet DF(x, z) + E'(y, z) \bullet DF(y, z)\} \tag{2}$$



(a) (b)

Fig.1: *A phantom with thin strings embedded in a lattice for investigation on effectiveness of surrounding elasticity information of the pressed point.*

x →, z ↓

0.8	0.2	0.0	0.0	0.0
0.7	0.2	0.1	0.0	0.0
0.6	0.3	0.1	0.0	0.0
0.5	0.3	0.1	0.1	0.0
0.4	0.3	0.2	0.1	0.0
0.3	0.3	0.2	0.15	0.05

Fig.2: *A part of Displacement Filter*

E'' : *elasticity at the position of the press for PHANToM Desktop^{TM}*

2.4 Calculation of the reaction force

Finally, the reaction force F presented by PHANToM DeskTop^{TM} is calculated in eqn.(3).

$$F = E'' \times d \tag{3}$$

This haptic rendering method can produce the accurate touch of the sense approximately by controlling parameters, EIP and DP in real time.

3. EXPERIMENTS

3.1 Experimental condition

It is required to set two parameters, EIP and DP properly to present the touch of sense for virtual palpation system, which is the same as one of real palpation. In this paper, the setting of EIP and DP are investigated experimentally. In this experiment, PHANToM DeskTop^{TM} is used as haptic device, which is shown in Fig.3

First, 4 phantoms whose elasticities are different each other are made. Next, a subject of the experiments touches the phantoms by a stylus which is similar to one of PHANToM DeskTop^{TM}. At a time, the subject touches virtual object by PHANToM DeskTop^{TM}. The subject adjusts EIP and DP as the virtual sense of touch becomes the same as the real sense of touch of the phantoms. Results obtained by some subjects are compared and investigated.

Fig.3: *PHANToM* DeskTop^{TM}

3.2 Phantoms for experiment

Four kinds of phantom are made for this experiment. The specifications are shown in Table 1.

Fig.4 shows a comparison of elasticity between the phantoms and tissues of female breast. Phantom1,2 and 3 correspond to normal tissue or benign tumor. Phantom4 corresponds to malignant tumor. Therefore, it is important problem that a subject can distinguish phantom4 from phantom1,2 and 3 by the proposed virtual palpation system or not.

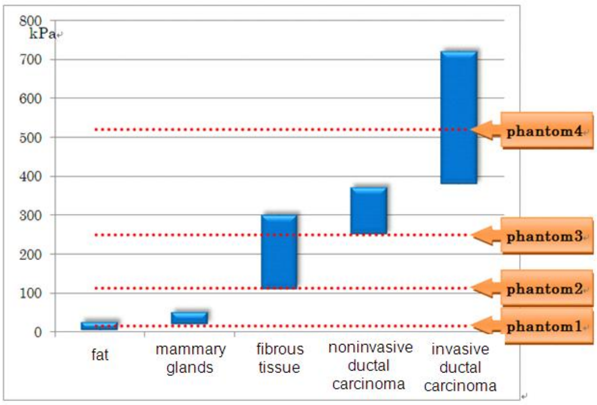


Fig.4: *Comparison of elasticity between phantoms and female breast tissues.*

3.3 Virtual object

The size of virtual object is 34×34 in x-y plane and 18 in depth. The resolution (voxel size) is 2.5mm cube. The size of DF in depth is 10. That means a subject can press the virtual object until 25mm in depth. The resolution (2.5mm) is determined from a human sense where the distance in which human sense can distinguish two points is 2-4mm.

3.4 Experiment-1

In this experiment, both EIP and DP are variable. The number of subject is 15 which consist of 10 males and 5 females in 20 years old generation.

The result is shown in Fig.5. The right side longitudinal axis shows DP and the left side one shows EIP.

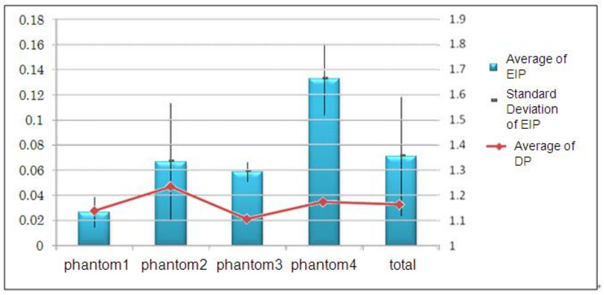


Fig.5: *The right side longitudinal axis shows DP and the left side one shows EIP.*

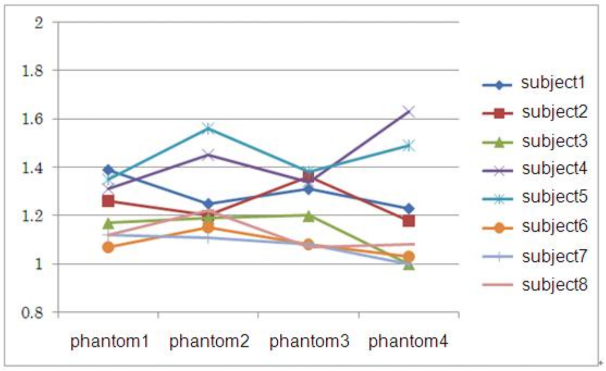


Fig.6: *DP setting in the case where EIP is fixed.*

All subjects could set EIP and DP as the virtual sense of touch of PHANToM DeskTop^{TM} becomes the same as the real sense of touch of phantoms. However, the averaged value doesn't correlate to elasticity of phantoms in the case of both EIP and DP. Furthermore, the standard deviation of EIP is large. That means the parameter setting depends on user. This result causes difficulty to set the parameters and to realize the proposed virtual palpation system.

3.5 Experiment-2

The reason why such result is obtained in Experiment-1 is estimated to be high correlation between EIP and DP and different standard value for each subject. Therefore, standard value for either EIP or DP is defined and fixed in Experiment-2. Realization of the proposed virtual palpation system is attempted by one parameter setting.

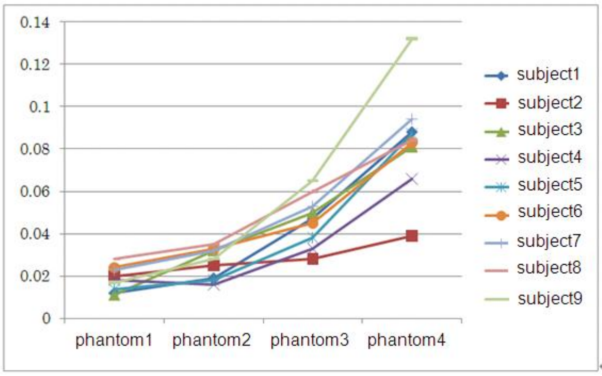


Fig.7: *EIP setting in the case where DP is fixed in 1.168.*

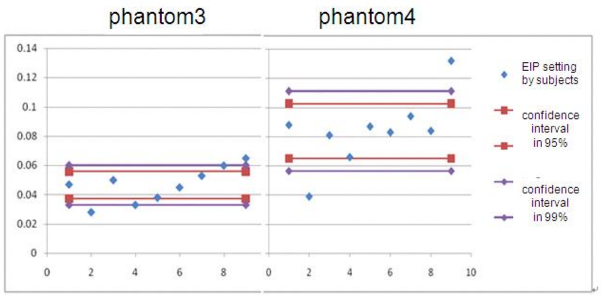


Fig.8: *Comparison of confidence intervals in t-test.*

3.5.1 The standard value for EIP

In this experiment, EIP is fixed for each phantom and only DP can be adjusted by a subject. The subjects consist of 6 males and 2 females in 20 years old generation. The standard values of EIP for each phantom are follows:

phantom1 : 0.0215
phantom2 : 0.0303
phantom3 : 0.0521
phantom4 : 0.1093

All subjects could set DP as the virtual sense of touch of PHANToM DeskTop$^{\mathrm{TM}}$ becomes the same as the real sense of touch of phantoms. The result of DP setting is shown in Fig.6.

Unfortunately, the DP setting doesn't correlate to elasticity of phantoms as well as Experiment-1. However, since the DP setting tends to be constant value and not to depend on elasticity and subject, it is estimated that DP should be fixed in a constant value.

3.5.2 The standard value for DP

In this experiment, DP is fixed in a constant value, 1.168 and only EIP can be adjusted by a subject. The constant value for DP doesn't depend on elasticity and subject. The subjects consist of 6 males and 3 females in 20 years old generation. All subjects could set EIP as the virtual sense of touch of PHANToM DeskTop$^{\mathrm{TM}}$ becomes the same as the real sense of touch of phantoms as well as previous experiments.

The result of EIP setting is shown in Fig.7. As the result shown in Fig.7, EIP setting corresponds to elasticity. Larger elasticity phantom has, larger EIP setting user selects. And its variance is also small. This result suggests that the proposed virtual palpation system can be realized by EIP setting according to elasticity measured by ultrasonic elastography without a parameter optimization (calibration) for each user.

However, the variance in the case of phantom4 is significantly larger than others. The border of benign tumor and malignant tumor is seated between phantom3 and phantom4 shown in Fig.4. Therefore, whether this border can be recognized or not is very important. This concern is investigated by using t-test.

As the result of t-test, it is confirmed that there is significant difference between phantom3 and phantom4. The result of comparison of a confidence interval in t-test is shown in Fig.8. This result shows that phantom 3 and phantom4 are obviously distinguished on the confidence interval in 95%.

3.6 Discussion

As the results of these experiments, it is shown that the proposed virtual palpation system can be realized by fixed DP and setting EIP from elasticity information measured by ultrasonic elastography without dependence on user.

4. CONCLUSION

The virtual palpation system has 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, a new haptic rendering method is proposed for the virtual palpation system. The haptic rendering method enables to realize re-producing elasticity of the point of press for PHANToM DeskTop$^{\mathrm{TM}}$ 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 results of experimental investigations show that the proposed virtual palpation system 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.

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