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# Cutaneous Tactile Synthesis for Cultural Heritage Exhibition

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**Abstract**

*The objects such as heritage objects can not be touched directly. Hence, some haptic devices were developed to permit users touch digital objects surface. These studies mainly confuse on developing haptic hardware, and the algorithm for synthesizing input signals were not studied well. A surface roughness measurement and input vibration signal synthesis techniques are proposed. To measure the surface roughness, some photos are taken using a fixed camera when the lighting changes its incidence direction. A surface normal image is obtained from these photos. Then vibration signal as input signal of cutaneous tactile device is synthesized. Adding the friction sound, the cutaneous tactile is enhanced and can got touch feeling well even using simple vibration tactile device. The system is consisted by 3D visual display, force feedback device and vibration tactile device. The effect of this system is demonstrated using virtual ancient heritage objects at the end.*

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [User Interfaces]: Haptic I/O

## 1. Introduction

Some studies were carried out for storing cultural heritage objects as digital data. But users can not touch them. A novel virtual reality (VR) exhibition system is designed to show the cultural heritage objects, and user can feel the force feedback and cutaneous tactile at same time. Noh (an ancient Japanese drama) mask and Japanese drawing shown in Figure 1 will be utilized as study objects to construct this exhibition system.


**Figure 1:** *Noh mask and Japanese drawing.*

This system is consisted of a 3D display and haptic devices. The 3D display becomes common place recently. This gives us a possible to show the 3D data easily. On another hand, the haptic technique is developed also. The haptic device named PHANTOM is utilized to represent the force feedback. The system for touching the surface of virtual object can be constructed based on the developed techniques. Figure 2 show the photo of this system. Users can watch appearance of objects and touch them. However, as the cutaneous tactile devices is developing now, these devices can simulate rough cutaneous tactile and is very difficult to obtain real one. To enhance cutaneous tactile, the algorithm for capturing object surface roughness is proposed and vibration signal as input signal of cutaneous tactile device are synthesized. The main objective of this study is not developing new hardware such as cutaneous tactile device. We hope enhance cutaneous tactile using software method. One idea is measuring real object surface roughness and synthesis vibration signal based on it. Another idea is using audio such as friction sound to enhance cutaneous tactile.

### 1.1. Previous work

As background knowledge, human cutaneous sensing function and the haptic devices are introduced at first. Then photometric stereo and vibration synthesis techniques are introduced.

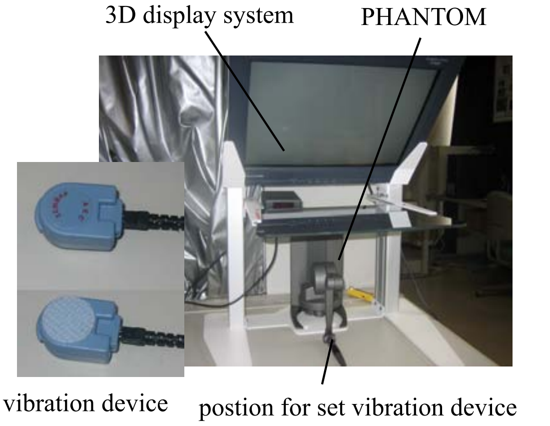


**Figure 2:** *The system composed by 3D display and haptic devices.*

Recently, some researches have been devoted to detailing the function of human cutaneous sensing ( [VJ84], [ODH98], [MAF07]). These works used sensor to study human touch sensing and give mechanism of cutaneous tactile. One find is that vibration or electric can cause cutaneous tactile. Based on this mechanism, some haptic devices for cutaneous tactile were developed ( [AMIM02], ( [KIKT04]). The vibration system is cheap and is utilized widely, but it is not easy to be controlled to obtain tactile reality. The input signals of electrical system are easy to be control, but this system is expensive and is developing now. In this study, the vibration system is utilized. To enhance the cutaneous tactile, the input signal synthesis algorithm is improved.

Even the devices for cutaneous tactile were developed, however, there are still very few experiments and research results in the area of modeling human touch sensing for purposes of allowing haptic experiments (especially tactile ones) on 3D objects in context of Cultural Heritage scenarios.

To synthesize vibration signals, it is necessary to know the surface roughness which is a geometric parameter. Constructing the geometric parameter such as the normal on the surface from photo is researched well. The principle of photometric stereo ( [Woo80]) can be used to construct the geometric parameter. The normal of surface can be obtained by the color variation of different photos or video ( [RTG97], [PF02], [RGG*03]). Comparing the reflection of examples such as ball to the reflection of the target object under same illumination conditions, the geometric parameter of the target object can be computed ( [HS03]). To decrease the errors of measuring, we measure the data in high density and construct the normal map for synthesizing input signals of cutaneous tactile device.

To improve reality, some studies were devoted to synthesize sound ( [DYN03], [ASR05]). These studies focused on synthesizing sound based on physical theory. Some studies notice the connect between sound and tactile and were devoted to enhance tactile using sound ( [HMG03], [GGB01]). Inspired from these studies, we synthesize vibration signal based on the measured surface roughness data and use recorded friction sound to enhance the tactile.

### 1.2. Overview

Figure 3 show the compute process of our approach. At first, change the position of light source and camera and a lot of photos are taken. Then the surface normal and the parameters of the shading models are obtained. The appearance of Ukiyo-e are rendered using the shading model proposed in [YCT*07]. The vibration signal is obtained from normal map and the recorded friction sound is utilized to enhance tactile. At the end, the total system is constructed using 3D display, speaker, vibration tactile device and PHANTOM for force feedback.

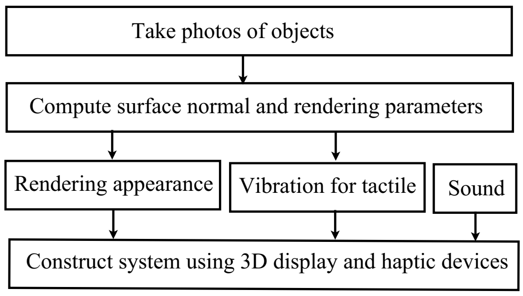


**Figure 3:** *The compute process.*

## 2. Measurement

We use a system named OGM (Optical Gyro Measuring Machine) to take photos of cultural heritage objects. OGM is 4 axes measuring machine which can put the light source and the camera on any position of a hemisphere dome.

The measured plane sample is put on the center of the stage. Figure 4 show the photo of OGM. As Noh mask is 3D model, it is difficult to be measured directly and a pigment plane sample is made and utilized to be measured. The Japanese drawing is plane and it is utilized to be measured directly. When measuring the color variation on objects, the camera is fixed on the position perpendicular to the surface of samples. The position of light source is changed. The record of the position in computer is a 2D array. To correspondent the 2D array and the position of lighting source on the hemisphere dome, a uniform concentric map ( [SC97]) is utilized to set the position of light source. A high density 361 by 361 grids is utilized to set the lighting position. To calibrate the light distribution on the surface, the photos of a white paper are taken also. The technique of [JDA05] is used to calibrate image color.

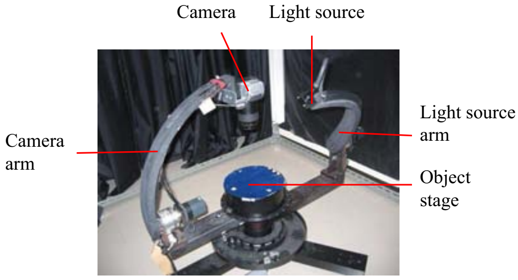


**Figure 4:** *Optical gyro measuring machine (OGM).*

**Figure 6:** *3D Noh mask model.*

### 2.1. Obtaining geometry parameter

The geometry parameter is the normal of micro geometric surface. Even the micro geometric surface shape can be obtained by integration from the normal, but we need not constructing the micro geometric surface. The information of the normal connect to rendering appearance, vibration signal synthesis for cutaneous tactile.

As enough density data are captured, it is easy to obtain normal $N$. It is know that the normal $N$ is in the middle of the strongest reflection $R$ and the lighting vector $L$. As the position of camera is fixed in measurement system, the reflection vector $R$ is fixed and is perpendicular to the sample surface. From the Bidirectional Reflectance Distribution Function (BRDF) captured by OGM, it is easy to obtain the lighting direction $L$ when reflection is strongest. Then the normal can be computed by $N = (L+R)/2$. The figure in Figure 5 is the image of plastic, Noh mask sample and Japanese paper samples surface normal. The value of $RGB$ represent the $XYZ$ value of normal $N$. (For print it clearly, the contrast is enlarged.)

## 3. Modeling and Rendering appearance

Main subject of this paper is developing algorithm for representing haptic information such as cutaneous tactile using traditional tactile device. The outline of modeling and rendering techniques utilized in this system are introduced as follow.

Noh mask and Japanese drawing are the cultural heritage object utilized in this system. Noh mask is 3D object and its original 3D rang images are obtained using a 3D shape scanner named VIVID 910. These rang images need be aligned together. The early align algorithm is Iterative Closest Point (ICP) algorithm. After that, a lot of align algorithms are developed to align rang images. Based on these algorithms, the software for aligning rang images was produced. The 3D Noh mask model is obtained using this type range images align software. As the color information is not good, some photos are taken by camera and mapped on the 3D model surface. Figure 6 shows the aligned 3D Noh mask model.

To represent appearance of Noh mask, traditional rendering technique (Torrance-Sparrow model) is utilized. Parameters of the rendering model are obtained by fitting them to the BRDFs measured by OGM.

To represent the appearance of Japanese drawing, the fiber reflection model is utilized as the fiber in Japanese paper is long. Shown as Figure 7, the blue plane is the normal plane $\Gamma$ perpendicular to the fiber direction $F$. The angle between the light vector $L$ and the normal plane $\Gamma$ is $\alpha_{if}$. The angle between the viewpoint vector $V$ and the normal plane $\Gamma$ is $\alpha_{rf}$. The reflection model of the fiber is developed from traditional reflection model such as Torrance-Sparrow model. The main difference between the fiber reflection model and the traditional reflection model is using the cone replace the vector of regular reflection. The effect of the fiber $I_f$ can be represented by next equation.

$$I_f = I_{df} + k_{sf} \bullet g(\sigma, \alpha_{hf})/cos^2(\alpha_{rf}) \tag{1}$$

Here, $I_{df}$ is the diffusion reflection of fiber. $k_{sf}$ is the specular reflectance of fiber. $g(\sigma, \alpha_{hf})$ is the normalized Gaussian same as the above. $\alpha_{hf}$ is the half-angle between the normal plane $\Gamma$ and the viewpoint vector $V$. All parameters can be obtained by fitting them to the measured BRDFs. The rendering result of Japanese drawing is shown in Figure 8.

## 4. Vibration signals synthesis

As mentioned above, the vibration signal is synthesized based on the measured surface roughness.

### 4.1. Friction model

When touch the surface and move finger, the friction phenomena occur. The friction phenomena are complex and are not understood well. Some friction models were proposed. The LuGre friction model is one of success friction model. This model is related to the bristle interpretation of friction.

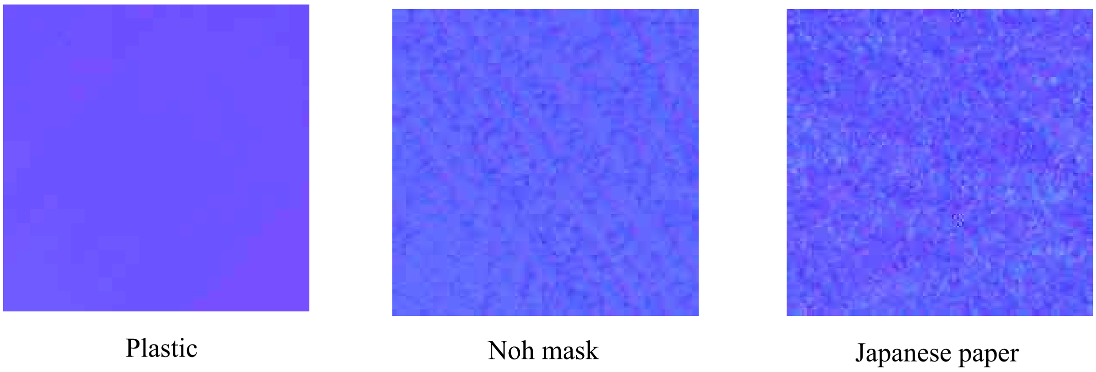


**Figure 5:** *The normal images.*

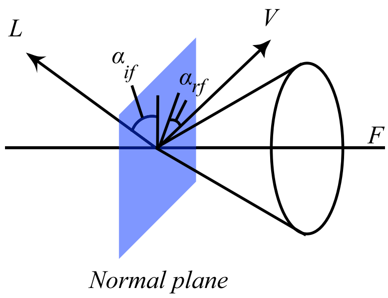


**Figure 7:** *Rendering model of fiber in Japanese paper.*


**Figure 8:** *Rendering result of Japanese drawing.*

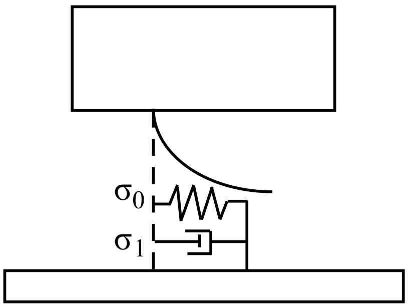


**Figure 9:** *LuGre friction model.*

The idea behind the bristle interpretation of friction is shown in Figure 9. It is assume that there are lots of bristles between two facing surfaces. The friction between the two surfaces is assumed to be caused by a large number of bristles, each contributing a fraction of the total friction. When the strain exceeds a certain level, the bond is broken.

Shown as Figure 9, the action of bristle can be represented as small stiff springs with dampers. When the object move on a rough surface, the displacement becomes too large, then, the junctions break and macroscopic sliding starts. Friction is modeled as the average deflection of the bristles. When a tangential force $f(v)$ is applied, the bristles deflect like springs. If the deflection is large enough, the Bristles start to slip. If $z$ denote average bristle deflection, $\sigma_0$ the stiffness of the bristles, and $\sigma_1(v)$ denote damping, this model is represented as follows.

$$F = \sigma_0 z + \sigma_1(v)(\partial z/\partial t) + f(v) \tag{2}$$

$\sigma_0$ and $\sigma_1(v)$ corresponds to the hardness of bristle. The largest deflection of bristle connect to the surface roughness can be represented using normal texture shown in Figure 5. Simulate the action of each bristle, the vibration of bristle can be obtained, this is input vibration signal for cutaneous tactile device.

### 4.2. Vibration signal synthesis

As mentioned above, the vibration signal for tactile device corresponds to the surface micro-structure. As this reason, the normal texture obtained above can be utilized to synthesize vibration signals for tactile device. The normal is 3D vector and has 3 value $XYZ$. If finger is moved on the surface, the move direction is tangent to surface. As this reason, largest deflection of bristle $z_{max}$ in LuGre connect to the value $X$ and $Y$ of surface normal.

The direction $D_p$ preventing object moving is inverse to the object moving direction $D_m$. Shown as Figure 10, $X_p$ is the value of the $X$ projection on the direction $D_p$ and $Y_p$ is the value of the $Y$ projection on the direction $D_p$. Then the largest deflection of bristle $z_{max}$ can be defined as $k \cdot (X_p + Y_p)$. $k$ is a constant in our model and show the relationship between surface roughness and largest deflection of bristle. Now, using surface normal and LuGre friction model can simulate the vibration of bristle.

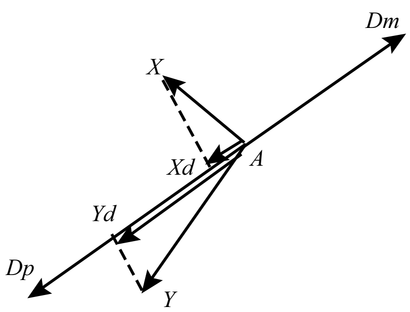


**Figure 10:** *Compute $z_{max}$.*

But the synthesized signal using this method is not nature and is a little far from the human feeling rhythm. To improve synthesized signal, it is necessary to process this signal. One process is cut white noise using low pass filter (LPF). As human cutaneous tactile is sensitive to the vibration on around 200Hz, the threshold for LPF is set to 500 Hz. After this LPF process, we add a natural noise to vibration. It is known that $1/f$ noise is one natural noise and near to the human feeling rhythm. This noise filter is shown as follow.

$$h = \sum (S/f^n) sin(f^n \omega) \tag{3}$$

Where, $S$ and $\omega$ are constant. $n$ is the number of trigonometric function. $f$ is constant and usually is 2. This filter is composed by a series of trigonometric function in which volatility and frequency is inverse proportion. After this process, the vibration signals are near to the human rhythm. The final synthesized result is shown in Figure 11. This signal will be played out by the tactile device.

## 5. Results

The system is constructed by a 3D display which gives 3D visual information, PHANTOM which show force feedback, speaker which plays friction sound, and vibration actuator device named VBW32C25. The cultural heritage object utilized here is a Noh mask and ancient Japanese drawing. The Noh mask pigment sample for BRDFs measurement was made by a Noh mask expert. This system has be exhibited in ASIAGRAPH 2008 ( [YNAT08]).

The experiment is devoted based on the GPU (Graphics Processing Unit) and can render objects on real time. The graph card is NVIDIA Quadro FX4500 which has a 3 pin stereo output for 3D display. In this 3D visual system, a LED device is utilized to translate the 3 pin stereo signal which comes from graphics card to infrared light, then switch left eye and right eye scene using a polarizing filter glasses. Using this method the 3D visual object can be seen in the space. The switch change speed is 140 Hz. The visual program is based on the OpenGL.

The PHANTOM is utilized to give force feedback. The collision decision between PHANTOM and virtual object is decided using the SDK of PHANTOM. Adjusting the parameters in program, this collision decision can be carried out on real time. The cutaneous tactile device is pasted on the tip of PHANTOM bar. User hold PHANTOM bar and put the index finger on the tactile device. When user touch virtual object, he can feel the force feedback and the vibration signal come from actuator as the cutaneous tactile. To enhance this cutaneous tactile, the recorded friction sound is play out via a speaker. The wave of recorded friction sound is shown in Figure 12.

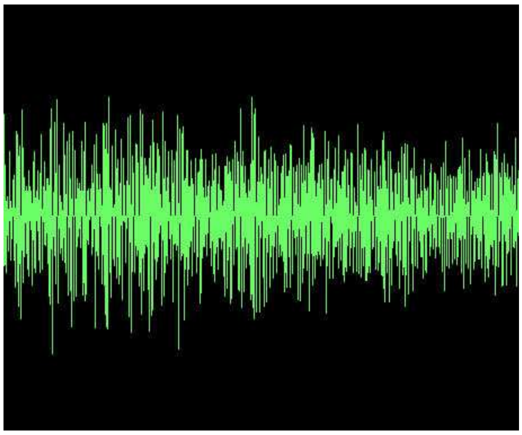

**Figure 12:** *Recorded friction sound (Noh mask).*

To evaluate this system, a questionnaire survey is carried out. Three conditions are set. First one (condition A) only show vibration signal for tactile. Second one (condition B) show the friction sound at same time, but its position is different to the PHANTOM tip where put the tactile device.

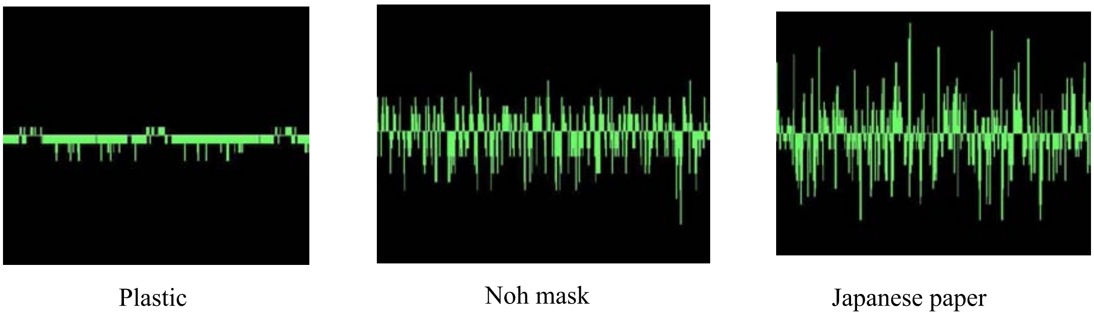


**Figure 11:** *Synthesized vibration signal for tactile device.*

Third one (condition C) show the friction sound at same time and its position is same as the tactile device. 11 users used this system and evaluate this system. The users give 0 to 2 points to the three conditions according to the cutaneous tactile. Feeling best cutaneous tactile, 2 points is given. The evaluate result is shown in Figure 13. It is clearly that the friction sound enhance the cutaneous tactile if the position is same as the position where is touched. But if the position is different from the position where is touched, the result is worst and even bad than the condition that is not friction sound.

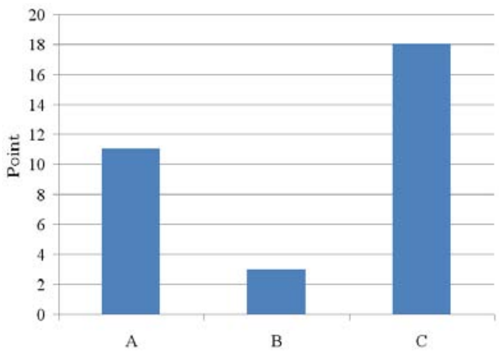


**Figure 13:** *Evaluate Results of the system.*

Experimentation is carried out to test if the user can identify the vibration signals. At first, the users touch the real surface of plastic, Noh mask and Japanese drawing samples. Then, let them touch the vibration signal and ask which material it is. For the plastic, the correct answer is nearly 100%. But for the Noh mask and Japanese drawing, the correct answer is not more than 65%. It is not easy to identify the Noh mask and Japanese drawing cutaneous tactile using this vibration system. One reason is that the pressure distribution is important for cutaneous tactile. Only using vibration can not represent rich cutaneous tactile. Another reason is that proposed vibration synthesis algorithm needs improving.

## 6. Conclusion

In this paper, a technique for enhance cutaneous tactile using vibration signal for tactile device and friction sound is proposed. Experimentations show that the friction sound is very useful to enhance cutaneous tactile when the position of the friction sound is same as the touched position. Since the heritage objects can not be touched directly, a non-contact measurement is also proposed to obtain roughness of heritage objects surface. Then, the roughness parameters are utilized to synthesize input vibration signal of cutaneous tactile devices.

The haptic devices for showing cutaneous tactile is developing now and there is far way to obtain tactile reality. We try to improve cutaneous tactile via improving the haptic input signal synthesis algorithm. However, the proposed vibration signal synthesis algorithm does not consider the finger deformation and function of human cutaneous sensing. In future, it is necessary to solve these issues. It is hope to use other cutaneous tactile device such as piezoelectric and electric type ones to test the proposed signal synthesis algorithm. This system can be easily developed to other application such as medical training, remote tactile communication and so on.

## Acknowledgments

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