Vibration Signal Synthesis for Representing Cutaneous Tactile

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Abstract

A surface meso-structure measurement and tactile device input vibration signal synthesis techniques are proposed. To measure the surface meso-structure, some photos are taken using a fixed camera with changing lighting incidence direction. A surface normal image is obtained from these photos. Then vibration signal as tactile device input signal is synthesized. Adding friction sound, the tactile is enhanced well even using simple vibration tactile device. The system is consisted of 3D visual display, force feedback device and vibration tactile device.

1. Introduction

Some objects can not be touched directly as they are expensive or very far from users position. A novel virtual reality (VR) system is designed to show this type objects, and user can feel the force feedback and cutaneous tactile at same time. 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 objects easily. On another hand, the haptic technique is developed also. The haptic device named PHANTOM (PHANTOM Desktop, produced by Sensable technologes) 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 1 show the photo of this system. Users can watch appearance of objects and touch them. However, as the 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 tactile device input signal 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 mesostructure and synthesize vibration signal based on it. Another idea is using audio such as friction sound to enhance cutaneous tactile.

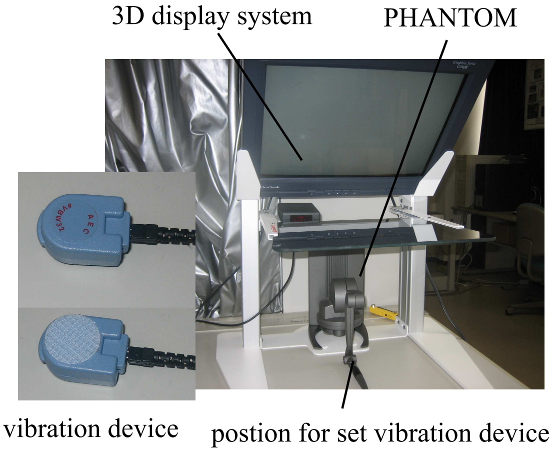

Figure 1. The system is consisted by 3D display and haptic devices.

1.1. Previous work

Recently, some researches have been devoted to detailing the function of human cutaneous sensing [6]. 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 [2, 4]. 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 proposed.

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. Some researches use sinewaves to synthesiz vibration signal for representing tactile ([5], [1]), however, these studies have not measured the surface meso-structure and not mentioned how to generate vibration signal from measured surface meso-structure.

To synthesize vibration signals, it is necessary to know

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the surface meso-structure 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 ([7]) can be used to construct the geometric parameter. 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 ([3]). These studies focused on synthesizing sound based on physical theory. Inspired from these studies, we synthesize vibration signal based on the measured surface meso-structure data and use recorded friction sound to enhance the tactile.

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.

3D objects are difficult to be measured directly and some plane samples are made and utilized to be measured. Shown as in Figure 2, three type samples such as plastic, Noh (Japanese drama) mask and Japanese paper are utilized. The Noh mask pigment sample for measurement was made by a Noh mask expert. 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 high density 361 by 361 grids is utilized to set the lighting position. The resolution of photo is about $60\mu m$ per pixel. When the finger moving speed is $3.0mm/s$, the vibration frequency is $50Hz$. It is enough to represent tactile.

Plastic Noh mask Japanese paper

Figure 2. Measured samples.

2.1. Obtaining geometry parameter

As the surface mesostructure parameter, the geometry parameter is the normal of micro geometric surface. Even the micro geometric surface shape can be obtained by integration from the normals, but we need not constructing the micro geometric surface. The information of the normals related to rendering appearance is enough for synthesizing tactile vibration signal.

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 3 is the image of plastic, Noh mask sample and Japanese paper samples surface normals. The value of RGB represent the XYZ value of normal N. (For print it clearly, the contrast is enlarged.)

Plastic Noh mask Japanese paper

Figure 3. The normal images.

3. Vibration signals synthesis

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

3.1. 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.

The idea behind the bristle interpretation of friction is shown in Figure 4. 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.

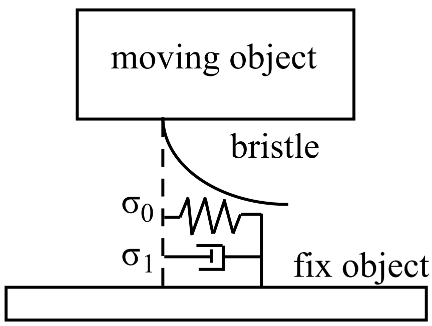

Figure 4. LuGre friction model.

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Shown as Figure 4, 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, σ_0 the stiffness of the bristles, and $\sigma_1(v)$ denote damping, this model is represented as follows.

$$F = \sigma_0 z + \sigma_1(v)(\partial z/\partial t) + f(v) \quad (1)$$

σ_0 and $\sigma_1(v)$ corresponds to the hardness of bristle. The largest deflection of bristle related to the surface roughness can be represented using normal texture shown in Figure 3. Simulating the action of each bristle, the vibration of bristle can be obtained, this is input vibration signal for cutaneous tactile device.

3.2. Vibration signal synthesis

As mentioned above, the vibration signal for tactile device corresponds to the surface meso-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 is relate 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 5, 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.

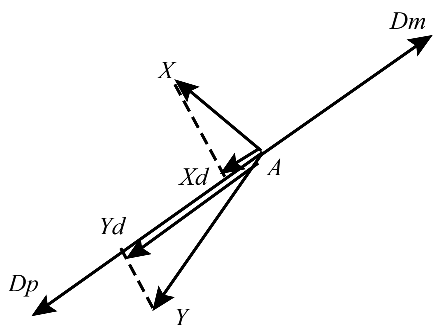

Figure 5. Compute z_{max}.

The compute process is shown as follow:

- Compute z_{max} using X and Y value of surface normals.
- Simulate friction between finger and object surface. If displacement z is bigger than z_{max}, finger move. At same time, a wave of vibration signal is obtained.
- Repeat above compute process until the finger stop moving on surface. Series wave of signal is obtained. This is original synthesized vibration signal wave.

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 cuting 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 signal. 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.

$$h = \sum (S/f^n) sin(f^n \omega) \quad (2)$$

Where, S and ω are constant. n is the number of sinewave function. f is constant and usually is 2. This filter is composed by a series of sinewaves 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 6. This signal will be played out by the tactile device.

4. Results

The system is consisted using a 3D display which gives 3D visual information, PHANTOM which show force feedback, speaker which plays friction sound, and vibration actuator device (VBW32C25, produced by Audiological Engineering Corp).

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 represent 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

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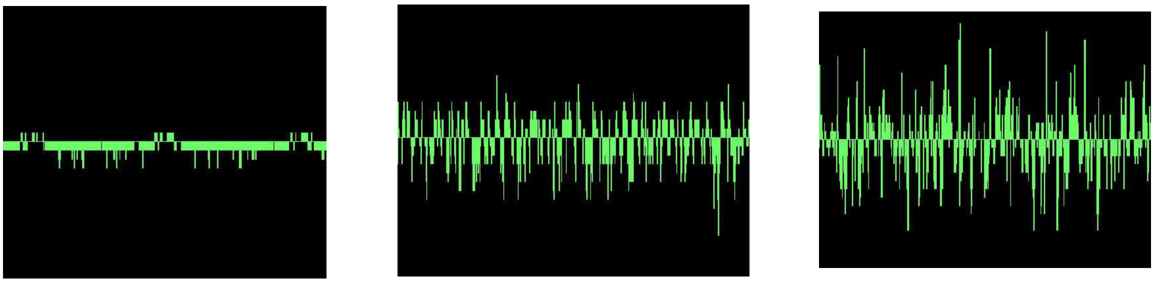

Plastic Noh mask Japanese paper

Figure 6. Synthesized vibration signal for tactile device.

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 tactile device.

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 answers are 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.

5. Conclusion

In this paper, a technique for enhance cutaneous tactile using vibration signal for tactile device and friction sound is proposed. A non-contact measurement is proposed to obtain objects surface mesostructure. Then, the mesostructure 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.

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