Roughness Sense Display Representing Temporal Frequency Changes of Tactile Information in Response to Hand Movements

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Abstract

We propose a hypothesis on mechanism of roughness perception based on temporal frequency changes of tactile information. Roughness sense can be considered as relative information to the hand velocity. Finite element analysis using human finger model showed that spatial information of the rough surface can be reflected in the temporal frequency changes at the position of tactile receptors. It should be important for roughness sense display to make a vibratory stimulation changing frequencies in response to the hand velocities.

1. Introduction

A tactile display technology to present more realistic touch feel including 'qualitative' information will realize advanced telemanipulation system directly connected to human dexterous skills and excellent sensibilities. Especially, roughness information is one of the most basic aspects of texture perception. Our main concern in this paper is a mechanical function of hand movements for roughness perception. Several researches showed the velocity of hand movements is not critical because roughness perception is unaffected over a wide range. However, roughness perception can be considered as relative information to the hand velocity, if human has the ability to know the hand velocities or the relative hand velocities to a rough surface. In this paper, we confirm that spatial information of the rough surface can be reflected in the temporal frequency information at the position of tactile receptors in the skin using FE analysis. we calculate the relationship between hand velocities and the temporal frequencies and amount of strain energy on each tactile receptors. Finally, we propose a method for roughness sense display based on the hypothesis of roughness cording.

2. A hypothesis on roughness perception

We proposed a simple hypothesis on roughness coding based on temporal frequency changes of tactile information (activities of FA I or SA I) in response to hand movements. We supposed that roughness perception is relative information to the hand movements. If human has the ability to know the hand velocity or the relative hand velocity to the surface using their deep sense, cutaneous sense, or motor commands in the central nerve, the spatial period of surface can be estimated by detecting the temporal frequency of vibration caused by stroking. If the surface has the same spatial period (wavelength: λ), the frequency f of vibration is relative information to the hand velocity V based on the following equation:

$$f = \frac{V}{\lambda} \qquad (\lambda : constant) \tag{1}$$

3. FE analysis

3.1. Methods

We analyze the deformation of a finger and the strain energy at the location of tactile receptors when the finger is in contact with the grooved surfaces, which was related to the perceived roughness[3], and slides on the surfaces. It is also known that SA I discharge impulse rate is in proportion to strain energy at the SA I location[1].

The FE model of finger is shown in Fig. 1. This model represents the complex structure of human finger tissue, such as multi-layered structure, the epidermal ridge, and the papillae in the dermis[2]. The geometry and material properties were determined by the measurement of human finger. The plane strain element was used because the deformation outside the modeled plane was negligible when the finger was moved in the x-direction. The black square and triangular symbols in the close view represent the nodes where FA I and SA I are located.

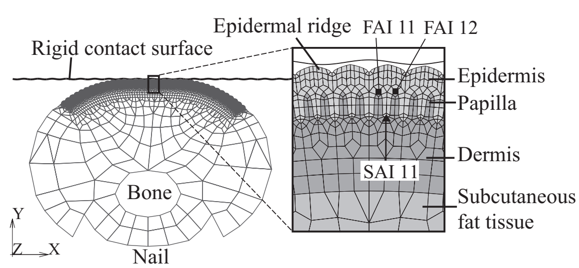

Figure 1. Finite element model of a finger section and location of tactile receptors.

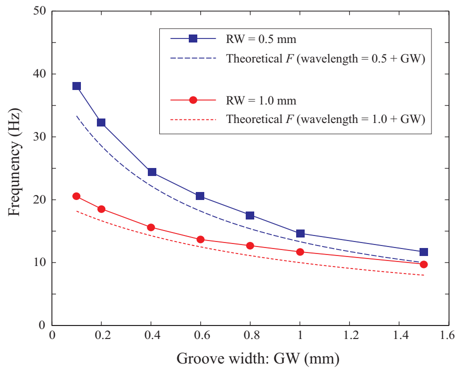

Figure 2. Grooved Width (GW) vs. the peak of strain energy spectrum at FAI 11.

To reproduce the deformation of a finger sliding on the grooved surface, we conducted static contact analyses when the rigid grooved surface slides on the finger model. The grooved surface is defined by Grooved Width (GW) and Ridged Width (RW)[3]. The contact movements are divided into three steps: (1) the grooved surface pushes the finger in the negative y-direction to a depth of 0.3 mm very slowly, (2) the grooved surface moves in the x-direction accelerating up to 20 mm/s within 0.5 sec, (3) the grooved surface moves in the x-direction at the constant velocity (20 mm/s) for 1 sec. The Coulomb friction model was used (the friction coefficient: 0.5).

We also conducted a contact analysis between the finger model and the rigid sinusoidal surfaces changing the sliding velocities to confirm the relationship between the hand velocity and the temporal frequency response. The wavelength and the amplitude of the sinusoidal surface is fixed at 1.0 mm and 2.5 μm, respectably. The thrust distance in the y-direction was 0.55 mm. The sliding velocities in the third step change from 5 mm/s to 30 mm/s by 5 mm/s.

3.2. Result

After obtaining the strain energy histories at the positions of FA I and SA I, we performed frequency analyses for the results of the constant velocity range (last 1 second).

Fig. 2 shows the relationship between GW and the frequency of the peak of strain energy spectrum at the FAI 11 for both RW = 0.5 and RW = 10. It was confirmed that the frequencies of the peak of strain energy spectrum at the both FAI 11 change in response to GW. The dashed lines are the theoretical frequencies assuming that the generated frequencies follow a wave equation (1), where wavelength λ is defined as $RW + GW$. The calculated frequencies were clearly agree with the theoretical values. It is notable that the tendency of the frequency change in response to GW is similar to the reported relationship between the perceived roughness and GW[3], assuming that the perceived roughness became larger when the frequency became smaller. This result indicates the possibility that the temporal frequency is related to the perceived roughness.

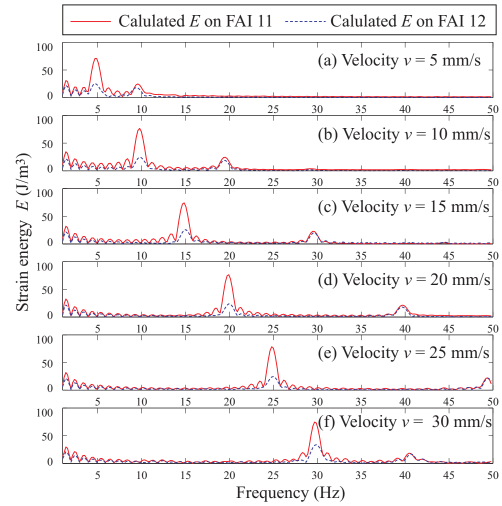

Figure 3. the strain energy spectrum vs. the hand velocities.

Fig. 3 shows the frequency responses of strain energy on each hand velocity. It is clear that the frequency at the peak of strain energy spectrum increase linearly when the velocity becomes higher. These results fully agree with the wave equation (1).

4. Conclusions

We proposed a hypothesis on mechanism of roughness perception based on temporal frequency changes of tactile information in response to hand movements. Finite element analysis showed that the spatial period of rough surface and the hand velocity can be reflected to the frequency of the strain energy at the location of FA I based on a wave equation theory. For realizing roughness sense display, representing frequency changes in response to the hand velocities and the spatial periods of rough surfaces can be a feasible method. Lately, we are confirming the validity of our method using a wearable ICPF tactile display[4],which can make a vibratory stimulation on fingertip in response to hand movements.

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