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M. Hirose, D. Schmalstieg, C. A. Wingrave, and K. Nishimura (Editors)

Short Paper: Characteristics of Perception of Stiffness by Varied Tapping Velocity and Penetration in Using Event-Based Haptic

Yuto Ikeda[†1] and Shoichi Hasegawa[†1]

[1]Room 521, East 4 Bld., 1-5-1 Chofugaoka Chofu-shi, Tokyo, 182-8585 JAPAN

Abstract

There are many works that uses event-based haptic to improve realism. We intend to investigate how the hardness presentation improves using event-based haptic, and how the perception of stiffness varies through presented vibrations.

In this short paper, we report about an experiment on point of subjective equality of stiffness. The result shows that both elasticity of the spring damper model and vibration affect subjective stiffness. In the result, there are large individualities. Analyses of the result based on velocities and penetrations of tapping suggest that larger velocities and penetrations give more correlations on stiffness of spring model and less correlations on presented vibration.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Line and curve generation

1. Introduction

Most of haptic interaction systems with impedance type haptic interface employ spring-damper models between haptic pointers and surfaces to calculate feedback forces. By adjusting spring-damper coefficients, conventional haptic interaction systems present stiffness of surfaces.

However, the method often lacks the realism, compared to real object. Conventional interfaces cannot present a stiff object as same as the real object because of instability of control [LB95]. Therefore, event-based haptic is suggested as a method to solve such a problem [PH95]. Their method presents physically-based vibration in addition to the force calculated from the spring-damper model. Fiene and Kuchenbecker propose that realism is improved by altering vibration depending on acceleration of the haptic pointer and changes in grip power [FK07]. Okamura et al. found that humans can perceive materials of object from physically-based vibration [OCD01]. In addition, Jean et al. suggested a method in which vibrations is altered based on position of contact point [JSA08].

As stated above, there are many works that uses event-based haptic to improve realism. We intend to investigate how the hardness presentation improves using event-based haptic, and how the perception of stiffness varies through presented vibrations. Kuchenbecker et al. found that presented vibration is important to realism of stiff objects [KFN06]. However their work focuses on evaluation of realism and not subjective stiffness. In contrast, in this short paper, we report about an experiment on point of subjective equality of stiffness.

2. Experimental Setup

2.1. Haptic Rendering

For feedback force, we use the proxy method [RKK97]. For vibration feedback, we employ Okamura‘s model, decaying a sinusoidal waveform:

$$Q(t) = A_q v e^{-B_q t} sin(\omega_q t) \quad (1)$$

where “t“ is time from the haptic pointer when contacted to an object, “Q(t)“ is the change in force from the vibration, “A_q“ is the amplitude coefficient,“v(t)“ is velocity that haptic pointer upon contact of an object, “B_q“ is the decaying coefficient, “ω_q“ is the sinusoid frequency. “A_q“, “B_q“, “ω_q“

[†] The University of Elctro-Communications

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are parameters peculiar to an object, and different vibration is presented by changing each value. This model is based on experiments and have similarity to vibrations of real objects.

The force from the vibration calculated in equation (1) is added to the feedback force from proxy method. The total feedback force is presented to the user via an haptic interface.

2.2. Haptic Interface and Controller

We employ string-based haptic interface "SPIDAR" developed by Makoto Sato [IS94]. The system is implemented by PC, WindowsXP OS with Intel Core Duo T2300 1.66GHz CPU. SPIDAR is connected to the PC by USB2.0 port. Using load cell, we experimentally confirm that SPIDAR can present vibration of up to 500Hz.

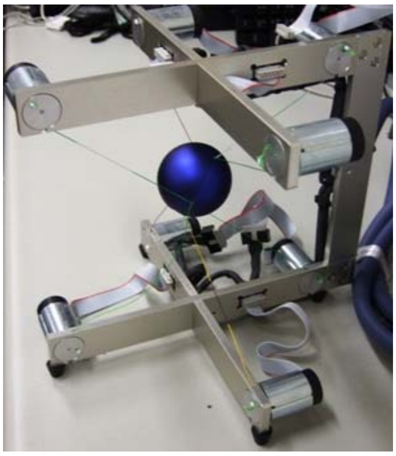

Figure 1: *The haptic interface "SPIDAR"*

3. Evaluation of Perception of Stiffness with Vibration

We tested how a stiffness perception varied by displaying vibration. We experimented using the adjustment method to find point of subjective equivalent for the perception of stiffness.

3.1. Experimental Protocol

The subjects were told to tap on a surface containing vibration as a control. They are asked to adjust the spring coefficient of a non-vibration surface to match the distinguish stiffness presented in the control. The 7 subjects were male and ranged in age from 22 to 26; they were used to use haptic interface.

3 spring coefficients (0.5N/mm, 1.0N/mm, and 2.0N/mm) and 2 types of vibration (aluminum like and wood like materials) were prepared and were presented as control (Table 1). Parameters in Table 1 are decided as a result having adjusted it in consultation with Okamura's paper.

Table 1: *Parameters of Presented Vibrations*

	$A_q(s^{-1})$	$B_q(ms^{-1})$	$\omega_q(Hz)$
vibration A(aluminum)	-1500	90	300
vibration B(wood)	-750	80	100

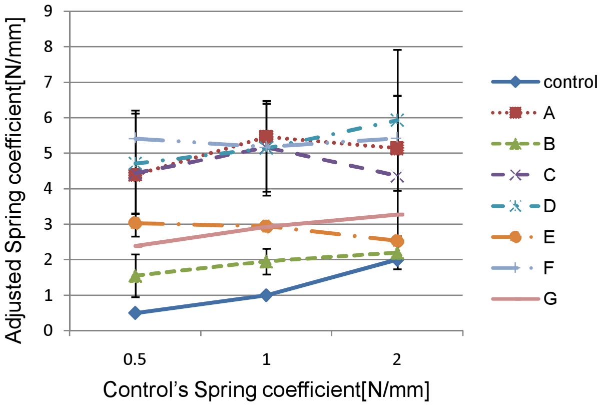

Figure 2: *vibrationA*

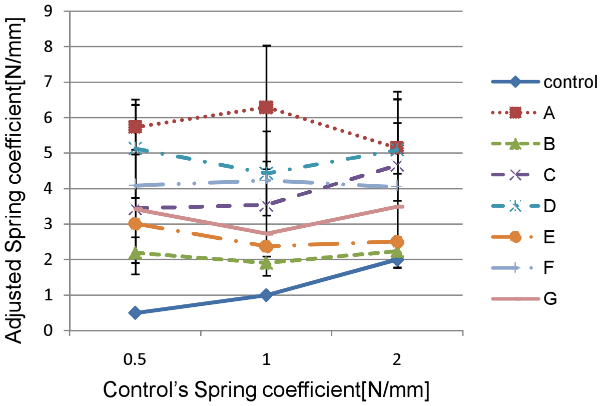

Figure 3: *vibrationB*

3.2. Result

Figure 2 and 3 shows the result of every vibration. When the vibration is presented, all subjects perceived stiffness more than spring coefficient of the controls. The perceived stiffness from the surface with vibration was not same for all subjects, and we found that perception of stiffness has individual difference.

Subject "B" as a representative was compared to subject "D". Here we can see that subject "B" did not perceive as much stiffness from the vibrations. The way of tapping on the surface is evaluated by the depth of penetration into the surface and the velocity of contacting the surface. Then we plot each of these measurements to the adjusted spring coefficient in every vibration (Figure 4-9).

Based on the results of each varied spring coefficient, subject “B“ and “D“ adjusted a low spring coefficient when the penetration depth gets deeper (Figure 4 and 7). When the penetration depth gets deeper, they tend to regard on the elasticity from the spring coefficient as a main clue to percept stiffness. In addition, when a control‘s spring coefficient increases, the penetration depth decreases and the adjusted spring coefficient increases.

When subject “B“ is compared to subject “D“, the penetration depth in subject “B“ is deeper than the penetration depth in subject “D“. By this result too, we assume that they regard the elasticity from the spring coefficient as a main clue to percept stiffness.

For the relation between the speed of a pointer and the spring coefficient, when the speed increases, the adjusted spring coefficient decreases (Figure 5 and 8). From the graph presenting the relation between the penetration depth and the speed of a pointer (Figure 6 and 9), we find that the penetration depth increases when the speed increases. Because of the fast speed of a pointer, the penetration depth increased. And as a result, subjects adjust the spring coefficient lower.

3.3. Conclusions and Discussion

The presented vibration is nearly as same as the natural frequency vibration to the fingertip as if when tapping on an object in the real world. As a result, the vibration could be one of the cues in stiffness perception. Humans perceive stiffness from both elasticity and vibration when tapping onto an object. The effect of the vibration becomes weaker when penetration depth increases while feedback force from the surface increases. In the experiment in [KFN06], contact velocity was controlled. We guess that the contact velocity was lower than that in our experiment.

In addition, there was a subject who got relatively low effect from vibration. As a result, we suppose that clues of elasticity and vibration work together in perceiving stiffness.

4. Future Work

We let our subjects tap freely in this experiment. As a result, individual differences occurred and the overall result was influenced. We felt that it is necessary to guide on how to tap on the surfaces to evaluate perception of stiffness from the vibrations.

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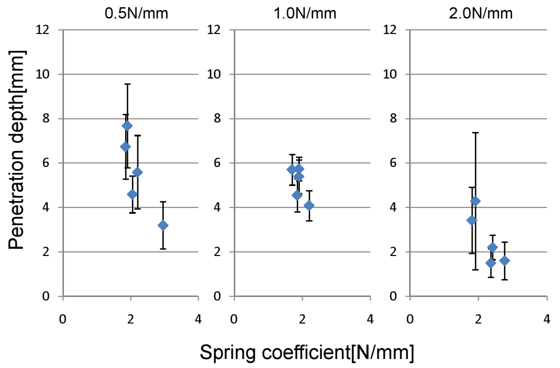

Figure 4: *the relation of the spring and depth (from Subject "B")*

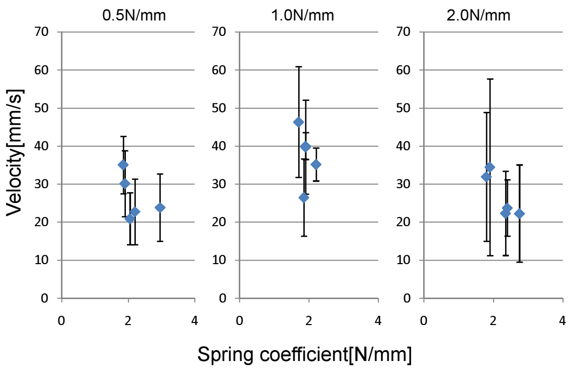

Figure 5: *the relation of the spring and velocity (from Subject "B")*

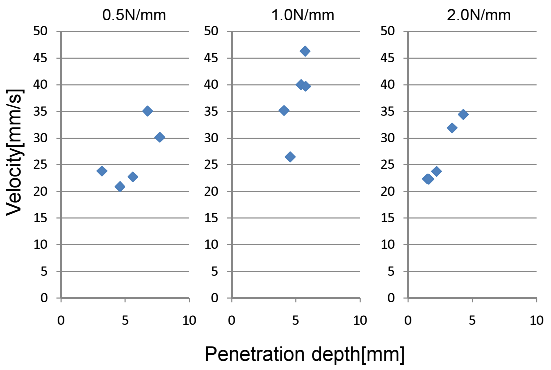

Figure 6: *the relation of the depth and velocity (from Subject "B")*

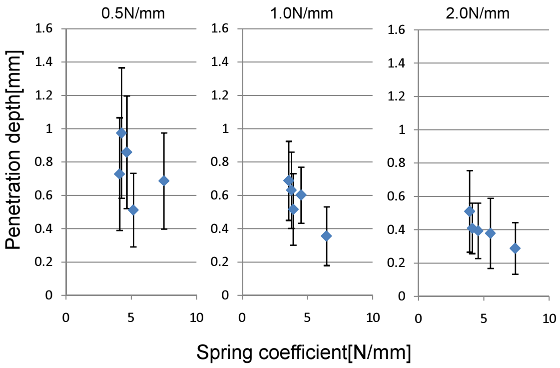

Figure 7: *the relation of the spring and depth (from Subject "D")*

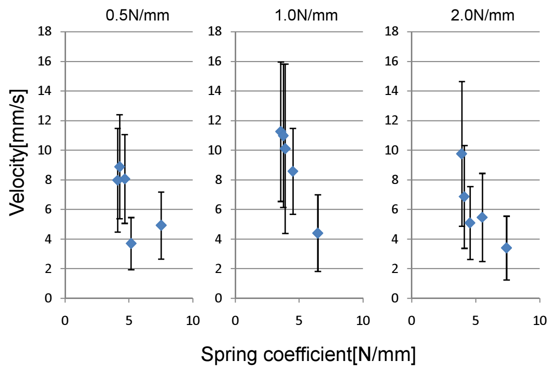

Figure 8: *the relation of the spring and velocity (from Subject "D")*

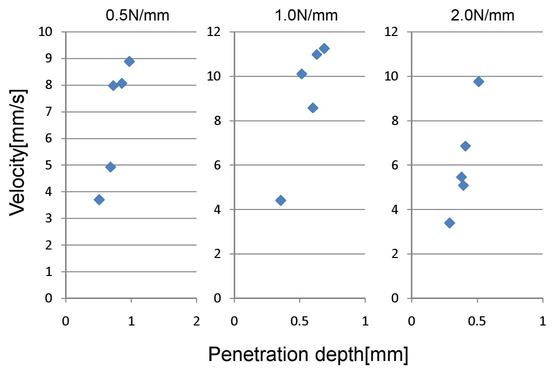

Figure 9: *the relation of the depth and velocity (from Subject "D")*