QoE Assessment of Adaptive Viscoelasticity Control in Remote Control System with Haptic and Visual Senses

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ABSTRACT

We propose adaptive viscoelasticity control which dynamically changes the elasticity and viscosity coefficients according to the network delay and the moving speed of a haptic interface device. We also investigate how large range the optimum viscosity coefficient has. We further obtain an equation that derives the optimum viscosity coefficient from the network delay and the moving speed by multiple regression analysis. Then, we examine the effectiveness of the control by QoE (Quality of Experience) assessment.

I. INTRODUCTION

Remote control systems in which users remotely operate haptic interface devices while watching video attract attention of a number of researchers [1]-[3]. In [1], Matsunaga *et al.* apply the adaptive elasticity control [2], which dynamically selects the optimum elasticity coefficient according to the network delay, to a remote control system with haptic and visual senses. The effectiveness of the control is also demonstrated by QoE (Quality of Experience) assessment. In [3], the authors propose the adaptive viscosity control, which dynamically selects the optimum viscosity coefficient according to the moving speed of a haptic interface device and the network delay. They also illustrate that the optimum viscosity coefficient has a certain range for a given network delay. If the two types of control are used in combination, higher quality of control may be realized. However, such a study has not been done so far.

Therefore, in this paper, we propose adaptive viscoelasticity control by combining the above two types of control. In the control, the equation obtained in [1] is used to determine the optimum elasticity coefficient according to the network delay. Then, we investigates how large range the optimum viscosity coefficient has for a given network delay and moving speed of the haptic interface device. We also obtain an equation that derives the optimum viscosity coefficient from the network delay and moving speed by multiple regression analysis. Then, we investigate the effectiveness of the control by QoE assessment.

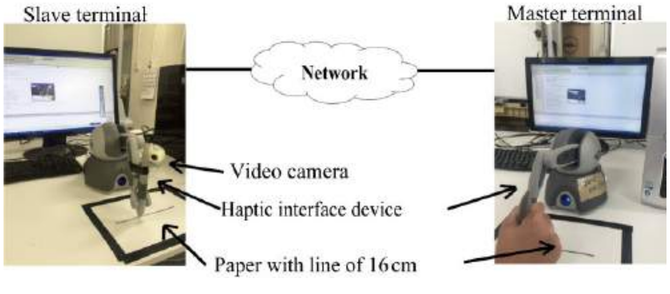

Fig. 1. Configuration of remote control system.

The rest of this paper is organized as follows. In Section II, first, we explain the remote control system with haptic and visual senses. Next, we describe the investigation method of the optimum viscosity coefficient and present investigation results in Section III. Then, we propose adaptive viscoelasity control in Section IV, and we describe the QoE assessment method and present assessment results in Section V. Finally, we conclude the paper in Section VI.

II. REMOTE CONTROL SYSTEM

Figure 1 shows the configuration of the remote control system with haptic and visual senses [1], [3]. In the system, a user at the master terminal can remotely operate a haptic interface device (Geomagic Touch) at the slave terminal by another haptic interface device at the master terminal. At the slave terminal, moving parts of the haptic interface device which are irrelevant to positional information are fixed with tape [1]. This makes it possible to write characters and draw figures without holding the stylus by hand. A video camera is connected to the slave terminal, and the user of the master terminal can do work while watching video.

III. INVESTIGATION OF OPTIMUM VISCOSITY COEFFICIENT

A. Investigation Method

As in [3], a line with length of 16 cm in the x axis direction is drawn on a paper placed in front of the haptic interface device of each terminal. Each subject moves the haptic interface device to the left and right along the line for 30 seconds. Since the reaction force due to the viscosity depends on the speed of moving the haptic interface device, the moving speed is set to 8.0 cm/s, 5.3 cm/s and 3.2 cm/ s. To find a range of the optimum viscosity coefficient, we obtain the value (called *optimum value 1* here) immediately before each subject has not felt improvement of operability of the haptic interface device and the value (*optimum value 2*) immediately before the subject has felt deterioration in the operability of the haptic interface device. The reason why there exists the optimum viscosity coefficient is as follows: If the viscosity coefficient is too small, the haptic interface device vibrates, if it is too large, the reaction force is too large. In the same way as in [3], we find optimum values 1 and 2. By taking account of fluctuations in the network delay and moving speed, we adopt the average value of optimum values 1 and 2 as the optimum viscosity coefficient. In this paper, we select the optimum elastic coefficient from the network delay by using the equation obtained in [1].

There were 15 subjects. The experiment took about three hours per subject.

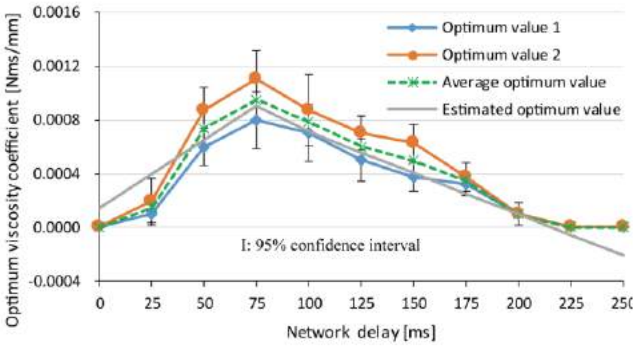

Fig. 2. Optimum viscosity coefficient versus network delay.

B. *Investigation Results*

We show optimum values 1 and 2 versus the network delay in Fig. 2. We also show the average of optimum values 1 and 2. Since almost the same trend was found for the three moving speeds, Figure 2 plots only results of the moving speed of 8.0 cm/s.

From Fig. 2, we can confirm that there is a certain range of the optimum viscosity coefficient for each network delay. Also, as the network delay increases, optimum values 1 and 2 become larger, but they start to decrease when they increase to some extent (that is, the optimum values have the peaks). This is because the reaction force becomes larger as the network delay increases. Then, stronger force is required to move the stylus of the haptic interface device. This makes it difficult for us to feel vibration.

IV. ADAPTIVE VISCOELASTICITY CONTROL

We here obtain two equations of the estimated optimum viscosity coefficient $\widehat{K}_{\rm d}$ (Nms/mm) before and after the optimum viscosity coefficient has the peak value $D_{\rm peak}$ (ms). First, we obtained the following equation of $D_{\rm peak}$ by regression analysis from the moving speed v (cm/s).

$$D_{\rm peak} = -20v + 228.$$

The contribution rate of this equation was 0.88. Thus, we can say that $D_{\rm peak}$ can be estimated with high accuracy from v. Then, we obtained the following equations of $\widehat{K}_{\rm d}$ by multiple regression analysis from the network delay D (ms) and v.

$$\widehat{K}_{\rm d} = \begin{cases} 1.02\times10^{-5}D + 4.2\times10^{-5}v - 2.03\times10^{-4} \ (D \leqq D_{\rm peak}), \\ -6.13\times10^{-6}D - 2.12\times10^{-4}v + 2.99\times10^{-3} \ (D > D_{\rm peak}). \end{cases}$$

Since the contribution rates of the above equations were 0.91 and 0.81, respectively, we can say that $\widehat{K}_{\rm d}$ can be estimated with high precision from D and v. Figure 2 also includes the estimated optimum value by using the above equations in Fig. 2.

V. QoE ASSESSMENT

A. *Assessment Method*

As in Section III, we changed the network delay and made the assessment. We presented the cases in which the viscosity coefficient has fixed values and the case of the estimated optimum value in random order for each subject. The subject gave a score according to the five grade impairment scale (5: Imperceptible, 4: Perceptible, but not annoying, 3: Slightly annoying, 2: Annoying, 1: Very annoying) compared with the operability of the haptic interface device when network delay is 0 ms. We obtained the mean opinion score (MOS) by averaging scores of all the subjects.

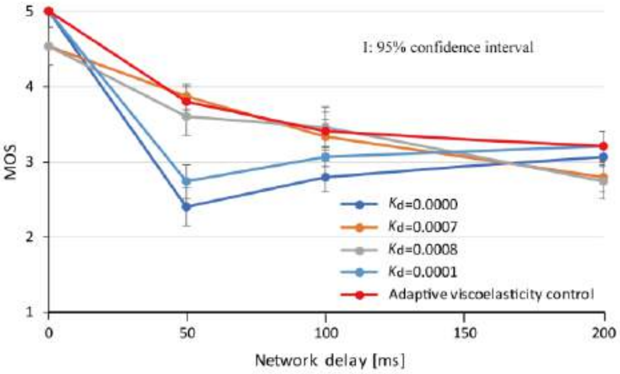

Fig. 3. MOS versus network delay.

B. *Assessment Results*

Since almost the same trend was found for the three moving speeds, we show only results of the moving speed of 8.0 cm/s in Fig. 3.

In the figure, we see that MOS of the adaptive viscoelasticity control is almost the highest in the whole range of the network delay considered here. We also find that MOS of adaptive viscoelasticity control is close to MOS when the optimum value of the viscosity coefficient is selected for each network delay. Therefore, it can be said that the control is effective.

VI. **CONCLUSIONS**

In this paper, we proposed the adaptive viscoelasticity control by combining the adaptive elasticity control and adaptive viscosity control according to the network delay and the moving speed of the haptic interface device. We also investigated how large range the optimum viscosity coefficient has. We further obtained an equation that derives the optimum viscosity coefficient from the network delay and moving speed by multiple regression analysis. In addition, the effectiveness of adaptive viscoelasticity control was demonstrated by QoE assessment.

In our future study, we need to examine dynamic behaviors of the adaptive viscoelasticity control when the network delay and moving speed are changed.

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