ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

Stiffness Sensing on Sensory Conflict of Visual Information and Haptic Information

Dong Il Park, Hyunmin Do, Chanhun Park and Jin-Ho Kyung
Korea Institute of Machinery and Materials

Abstract*— Haptics refer to technology which interfaces the user via the sense of touch by applying forces, vibrations and motions to the user to enhance the remote control of machines and devices. It is a key part of virtual reality systems, adding the sense of touch to previously visual-only solutions. Therefore, both the visual information and the haptic information are important for human sensitivity in the remote controlled system and the teleoperated system. In the paper, effect of virtual information on human sensitivity is analyzed when human senses the stiffness of the virtual spring which is exerted by haptic device. Sensing the spring stiffness using haptic information alone is compared with sensing it using both haptic and visual information. Because visual information on the monitor is served as virtual displacement which is different from real displacement, it can work on sensory coherence or sensory conflict. Sensory coherence means visual information help with sensing the stiffness variation controlling virtual displacement and sensory conflict indicates that visual information is served against the stiffness variation. To compare the stiffness of the varied spring with the stiffness of the reference spring, JND (Just Noticeable Difference) index is used. JND of sensory conflict degree and stiffness is measured with variation of the real spring stiffness exerted by haptic device. Consequently, we found that sensory conflict has a tendency to increase JND of stiffness variation by about 6~24%.

Index Terms—**Sensory conflict, JND, Haptic illusion.**

I. INTRODUCTION

Haptics refer to technology which interfaces the user via the sense of touch by applying forces, vibrations and motions to the user to enhance the remote control of machines and devices. It is a key part of virtual reality systems, adding the sense of touch to previously visual-only solutions. Therefore, both the visual information and the haptic information are important for human sensitivity in the remote controlled system and the teleoperated system. It is necessary to investigate how the virtual information and the haptic information affect human sensitivity. There have been many research activities about the integration of haptic information and visual information.[1-4] Research on haptic illusion is also abundant, including the research project on the phenomenon of illusion which occurs with pseudo-haptic feedback using two kinds of virtual springs with differences between visual information and haptic information.[5-12] However, the previous researches didn't consider the standard of force boundary and displacement and didn't take into account individual differences. In the paper, effect of virtual information on human sensitivity is analyzed when human senses the stiffness of the virtual spring which is exerted by haptic device. Sensing the spring stiffness using haptic information alone is compared with sensing it using both haptic and visual information. Many experiments for various force and displacement are carried out and effect of sensory conflict degree was analyzed.

II. STIFFNESS SENSING

This paper is dealing with the degree of human perception of change when visual information provided is in conflict with actual haptic information. Basic concept of human sensing is represented as Fig. 1. Effect of virtual information on human sensitivity is analyzed when human senses the stiffness of the virtual spring which is exerted by haptic device. Sensing the spring stiffness using haptic information alone is compared with sensing it using both haptic and visual information. To compare the stiffness of the varied spring with the stiffness of the reference spring, JND(Just Noticeable Difference) index is used. JND is the smallest difference in a specified modality of sensory input that is detectable by a human being. JND of sensory conflict degree and stiffness is measured with variation of the real spring stiffness exerted by haptic device. Many experiments for various force and displacement are conducted in order to determine the threshold, because JND is a statistical, rather than an exact quantity. We analyzed the difference of JND (Just Noticeable Difference) between when real visual information is provided and when visual information in conflict with stiffness variation is provided, thereby verifying sensory conflict degree between haptic information and visual information..

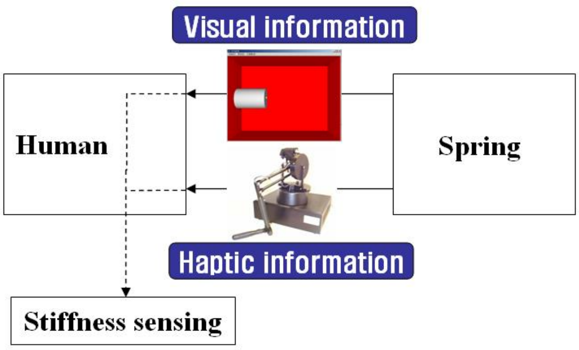

Fig 1 Stiffness sensing using haptic and visual information

In order to sense the stiffness of a spring, humans consider two types of information that they perceive, namely force and displacement. Haptic information obtained from haptic devices alone can still make humans sense stiffness, but by adding visual information, the sensitivity of stiffness sensing can change. For instance, assuming that humans can detect

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ISO 9001:2008 Certified
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changes of stiffness, it will help them to sense changing stiffness more easily when visual displacement information smaller than real displacement is provided. Likewise, visual displacement information bigger than real displacement makes it more difficult for humans to detect change of stiffness. In other words, sensory coherence of two types of information increases sensitivity of stiffness sensing, while sensory conflict has the opposite effect. The next chapter will show quantitative analysis of sensory conflict degree through an experiment.

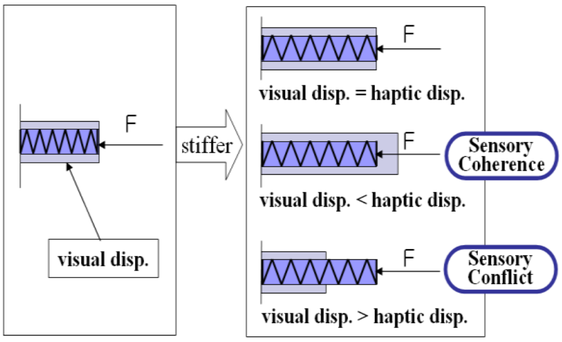


Fig 2 Comparing stiffness with sensory conflict

III. EXPERIMENT

A. Experimental setup

Like what was mentioned above, a haptic device is an instrument that enables remote controlling and real-time sensing of force feedback and motion. The PHANToM device shown as Fig. 3 was used as the force feedback device. By using this device, 1-axis horizontal spring with variable stiffness is implemented. Visual information is displayed in the form of cylinder blocks on the computer monitor as shown in Figure 4, which is synchronized with the moves of the haptic device. to analyze the effect of force and displacement, a total of nine test sets are set up as shown in the table 1. Each test set was put through three identical tests to minimize experimental errors.

Fig 3 PHANToM - Haptic device

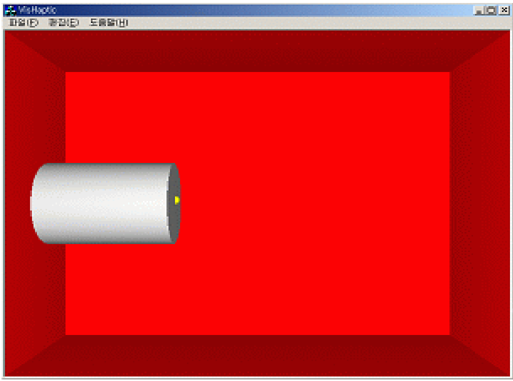


Fig 4 Virtual spring on the monitor

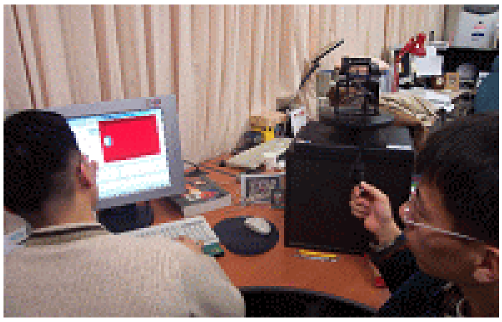
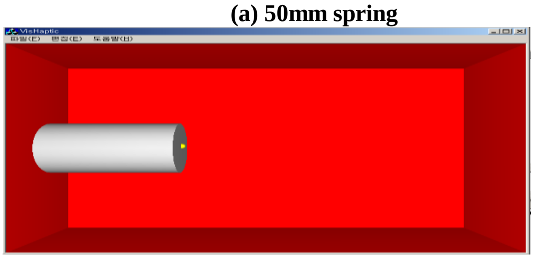


Fig 5 Experimental setup

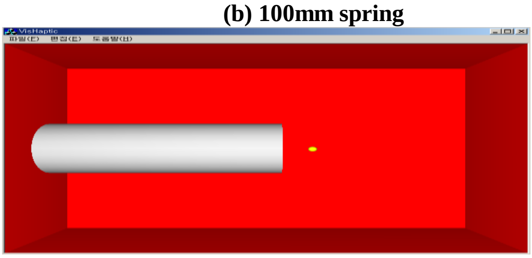
Table 1 Reference spring set

	50mm	100mm	150mm
1.0N	1	2	3
2.5N	4	5	6
4.0N	7	8	9

(a) 50mm spring



(b) 100mm spring



(c) 150mm spring
Fig 6 Reference spring set

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ISO 9001:2008 Certified
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For east test set, a pair comparison test was conducted by making the subjects sense the reference spring and then the comparing spring. The subjects were blindfolded to deprive them of visual information when they were to sense stiffness using only haptic information. Comparison test subjects were provided with virtual information from the monitor. For east test set, visual displacement and force range remained constant while sensory conflict degree was adjusted. In this experiment, sensory conflict degree (C) is defined as the ratio of visual displacement (D_v) to haptic displacement (D_h), and the value ranged from 0.4 to 1.6 as shown below.

$$D_h = C \times D_v$$

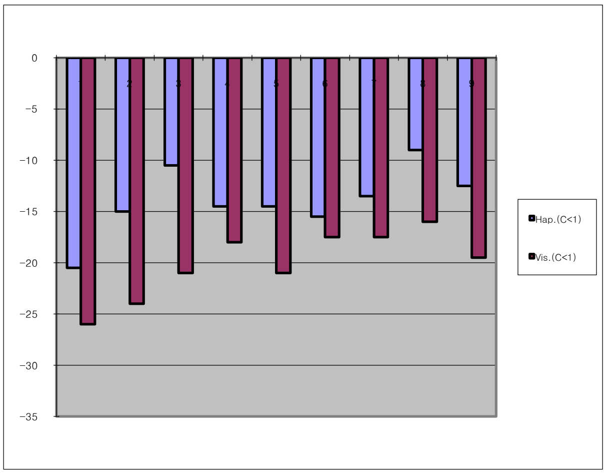
where C = [0.4 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.6]

To minimize the influence of individual difference, the same tests were conducted on 10 different individuals, each with approximately 500 times of tests. As mentioned above, JND—JND is the smallest difference in a specified modality of sensory input that is detectable by a human being—was investigated.

B. *Experimental results*

Table 2 below show 1) how humans sense the stiffness of the spring when given constant force and changing real displacement and visual displacement, and 2) how much change of real displacement and visual displacement makes them feel the stiffness of the spring unchanged. In other words, the tables show how sensory conflict reduces sensitivity of humans in comparison to their sensitivity under haptic information alone.

(a) C>1



(b) C<1

Fig 7 JND of C(=Dh/Dv) for each test set

Table 2 JND increase of C for each test set

	50mm	100mm	150mm
1.0N	24	16.5	12.5
2.5N	18.5	10.5	7
4.0N	7.5	7.5	3

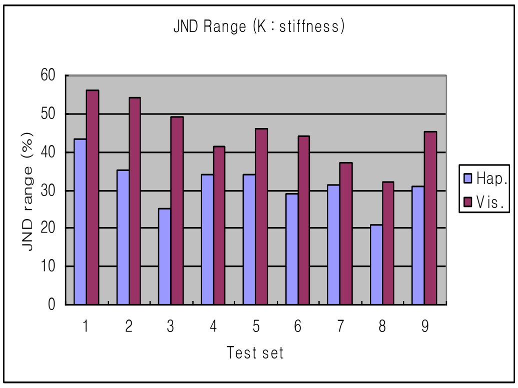
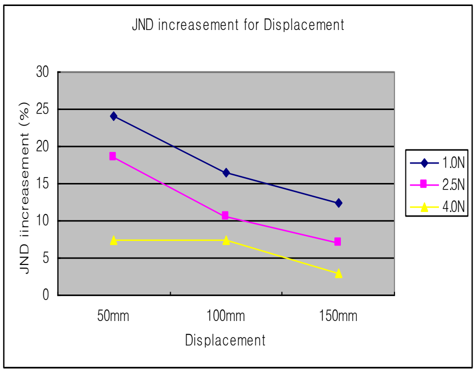
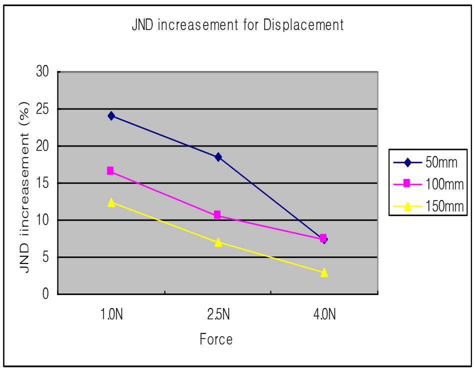


Fig 8 JND range of C for each test set

When the subjects were given only haptic information, JND is 17.7 percent when C>1, and –14 percent when C<1. When conflicting visual information is also provided, JND is 23.4 percent when C>1, and –20.0 percent when C<1. The range of JND, thus, is increased by 11.9 percentage points from 31.5 percent to 43.4 percent. The result of analysis of effect of force and displacement for each test set is shown in table 2. When the force and displacement is smaller, the influence of visual information grows, and the JND increases by up to 24 percent.



(a) For displacement



(b) For force

Fig 9 JND increase of C for displacement and force

Converse it to sensitivity to stiffness and the result is what is shown in the figure and table 3. Here, each stiffness of reference spring (K_r) and stiffness of comparing spring (K_c) is decided by the following formulas:

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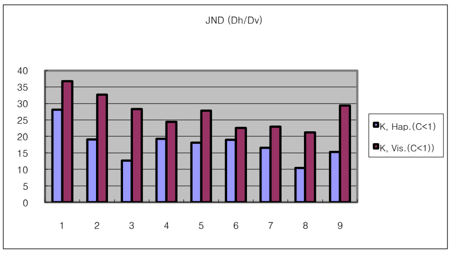
$$K_r = F_{\max} / D_v$$
$$K_c = F_{\max} / D_h$$

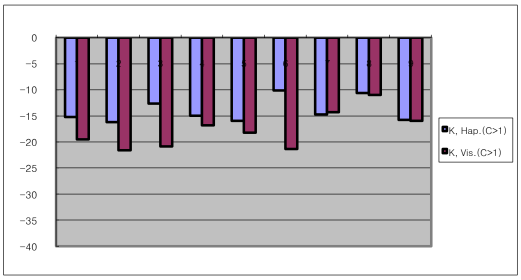
When haptic information alone was given, JND changed by 17.6 percent when stiffness increased and by –14 percent when stiffness decreased. When conflicting visual information is additionally provided, JND changed by 27.4 percent when stiffness increased and by –17.7 percent when it decreased. Variation of stiffness accounted for an average 13.5 percent increase of JND range. The result clearly shows that the smaller the force and displacement are, the bigger the sensory conflict effect is, and that fluctuation of force and displacement brings about 6-24 percent decrease of sensitivity.

Table 3 JND increase of K for each test set

	50mm	100mm	150mm
1.0N	23.88	18.99	12.94
2.5N	14.85	12.03	7.04
4.0N	14.21	11.13	5.95



(a) K>Kr



(b) K<Kr

Fig 10 JND of K for each test set

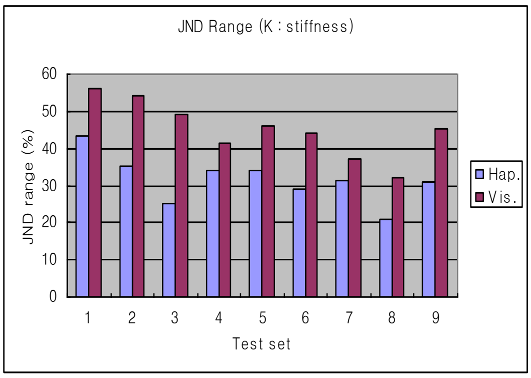
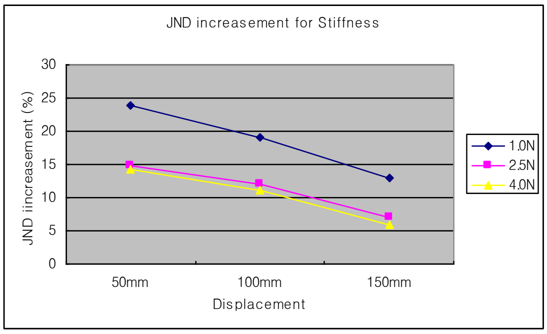
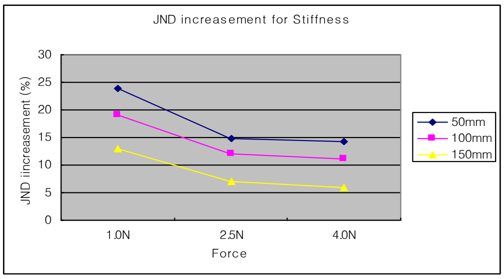


Fig 11 JND range of K for each test set





(b) For force

Fig 12 JND increase of C for displacement and force

IV. CONCLUSION

Effect of virtual information on human sensitivity is analyzed in this paper when visual information is served as sensory conflict in addition to haptic information. To conclude, sensory conflict has a tendency to increase JND of stiffness variation by about 6~24 percent, although JND of sensory conflict degree is different by individuals. Also, the analysis confirms that the smaller the force and displacement are, the bigger the effect on sensitivity is. It is proved that sensory conflict makes sensitivity of humans decrease as shown in the experiment while human sensitivity generally increases in the case of sensory coherence. The analysis result is expected to be more accurate if improvement can be made in largely four areas: the limited range of data set imposed by force and displacement limit of the haptic device, fatigue level of the subjects, the limited number of subjects, and sensory conflict resolution.

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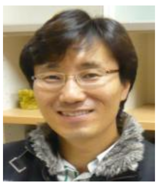
AUTHOR BIOGRAPHY

Dong Il Park received a BS degree in Mechanical Engineering from Korea Advanced Institute of Science and Technology (KAIST) in 2000, a MS degree in Mechanical Engineering from KAIST in 2002 and a PhD degree from KAIST in 2006. He has been researching the robotics in Korea Institute of Machinery and Materials (KIMM) since 2006. His research fields are the design, control and application of robot manipulators and mobile robots.

Hyun Min Do received the B.S. and M.S., and Ph.D. degrees in the School of Electrical Engineering from Seoul National University, Seoul, Korea, in 1997, 1999, and 2004, respectively. From 2007 to 2010, he was the National Institute of Advanced Industrial Science and Technology, Japan, where he was a Postdoctoral Research Fellow. In 2010, he joined the Korea Institute of Machinery and Materials, where he is a Senior Researcher of Robotics and Mechatronics Research Center. His research interests are neuro computing and control, adaptive and learning control, ubiquitous robotics and robot middleware, mobile robot navigation, and manipulator control of a dual-arm robot and a parallel kinematic machine.



CHAN HUN PARK received BS degree in Mechanical Engineering from Yeungnam University, Korea, in 1994 and MS degree in Mechanical Engineering from POSTECH, Korea, in 1996 and PhD degree from KAIST, in 2010. He has been working for Korea Institute of Machinery and Materials (KIMM), Korea, since 1996, where he is currently a senior researcher. His research fields include human-robot cooperation and design and control of dual arm robot manipulator for industrial applications.

JIN-HO KYUNG received his B.S. and M.S. degree in Mechanical Engineering from Korea Aerospace University and KAIST in 1985 and 1988, respectively. He was awarded his Ph.D. degree from KAIST in 2003. Dr. Kyung is currently a Principal Researcher at Dept. of Robotics & Intelligent Machinery at Korea Institute of Machinery and Materials, and he has served as a head of Robot team. Dr. Kyung's research interests include the design and control of robotic systems, and manipulation technology for human-robot cooperation.