Development of a Haptic Device Expressing Hardness of the Virtual Object Using Solenoid

SHENJING CHEN* Non-member, YUYA KAWAHARA* Non-member
AKIRA YAMAWAKI* Member, SEIICHI SERIKAWA* Member

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Abstract: As one kind of new input device or new information exhibition device, haptic devices representing a tactile feeling of the object are actively researched in recent years. However, the current haptic devices might cause some discomfort or inconvenience when being used. There are two reasons for this: (1) Certain devices need be attached to fingers. (2) Dedicated and exclusive apparatus and panels are needed. Therefore, in this paper, we propose a new haptic device which is simple but can show the hardness of the virtual object using solenoid. By putting the existing touch panels such as smartphones or tablets on this device, the whole apparatus can be used for the measurement of tactile feeling. The device reproduces reaction force to fingers when the object is displace through the control of solenoid voltage, and shows the hardness of the virtual object. The result of the preliminary experiment measuring the reaction force on prototype devices shows that it is possible to control reaction force using solenoid. In addition, as an example of the application of this technique, we design a software keypad which can demonstrate the feel of buttons through images on its touch panel. Compared with the case when the hardness of the image buttons is not changed, our study demonstrates that the input is faster and the ratio of the mistaken key typing can be reduced when the hardness is changed using our technique.

Keywords: Haptic, Tactile, Solenoid, Control, Sensing.

1. Introduction

At present, touch panel equipped electronic devices like tablets, smartphones, and portable game players have been spreading around us. However, operation and information transmission of these devices are depending on eyesight. So, the problems will occur such as eye fatigue, or elderly people or visually impaired people are hard to use touch panel. Therefore, to solve these problems, haptic devices are gathering attention. Haptic devices reproducing the feel of the object have been actively researched in recent years. As one kind of new input device or new information exhibition device, haptic devices enable person and machine communication through touch. The areas of haptic devices are also growing rapidly including entertainment, welfare, robotics, psychology, biology, computer science, systems control, and others[1].

However, even though there are constant demands, haptic devices are not very common. This is because the current haptic devices might cause some discomfort or inconvenience when being used. There are two reasons for this:

(1) Certain devices need be attached to fingers

(2) Dedicated and exclusive apparatus and panels are needed.

Therefore, in this paper, we propose a new haptic device which is simple but can show the hardness of the virtual object using solenoid. By putting the existing touch panels such as smartphones or tablets on this device, the whole apparatus can be used for the measurement of tactile feeling. We develop a prototype device to investigate whether our device can actually exhibit hardness using solenoid or not. In addition, as an example of the application of this technique, we design a software keypad which can demonstrate the feel of buttons through images on its touch panel, and report experimental results of the touch panel.

2. Proposed System

2.1 System organization

Figure 1 shows the structure of proposed system. The device consists of a displacement sensor which detects movement of a fixed way, DC solenoids which exhibit hardness and a control unit which controls the displacement sensor and DC solenoids. Smartphones and tablets are put on the fixed way. According to the finger position on the touch panel and the movement of the fixed way, the voltage to DC solenoids is controlled by the pulse width modulation (PWM). The device reproduces reaction force to fingers by displacement of the object according to control voltage of the solenoid, and express hardness of the virtual object.

2.2 Hardness expression using solenoid
2.2.1 Structure of solenoid  Figure 2 shows the structure of DC solenoid[2]. DC solenoid consists of a movable iron core, and coil which generates a magnetic field. When electric current flows through the coil, the movable iron is drawn toward the fixed iron core by magnetism. Since magnetic strength changes by voltage, any force by the magnetic strength can be generated.

2.2.2 Principle of hardness change  The hardness of a material is expressed by Young’s modulus[3][4]. It is defined as the ratio of the uniaxial stress over the uniaxial strain. The formula of Young’s modulus $E$ is shown in Eq(1). Definition of young’s modulus is shown in Fig. 3. 

$$E = \frac{F}{S} \frac{\Delta x}{X} \quad (1)$$

where, $F$: stress, $S$: cross section, $\Delta x$: strain, $X$: length.

In Fig. 3 and Equation (1), $\Delta x/X$ expresses uniaxial strain, and $F/S$ expresses uniaxial stress.

Next, when solenoid puts strain ($F'$) from the bottom, an apparent Young’s modulus ($E'$) is shown in Equation (2) and Fig. 4.

$$E' = \frac{f}{\Delta x} \frac{F'}{X} = \frac{f}{S} \frac{F'}{S} \frac{\Delta x}{\Delta x} \frac{X}{X} = E \left( 1 + \frac{F'}{F} \right) \quad (2)$$

Figure 4 and Equation (2) indicates that the apparent Young’s modulus $E'$ changes in proportion to the strain ($F'$) from the bottom. So it is possible using solenoid to change the apparent hardness by changing the strain from the bottom.

3. Prototype Device  The block diagram of the prototype device is shown in Fig. 5, and the photographs of prototype device are shown in Fig. 6 and Fig. 7.

There is a fixed way which puts smartphones or tablets on the device, and a displacement sensor and four DC solenoids are put to underneath the fixed way. A displace-

![Figure 1: The structure of proposed system.](image1)

![Figure 2: Structure of solenoid.](image2)

![Figure 3: Definition of young’s modulus.](image3)

![Figure 4: Strain (F’) from the bottom.](image4)

![Figure 5: The block diagram of the prototype device.](image5)
ment sensor and each solenoid are connected to the control unit. The role of each part is shown below.

I. Touch panel such as smart phones, tablets, etc., determine the position of finger touching the screen.

II. PC communicates with the control unit using serial communication, and outputs the image to touch panel.

III. A displacement sensor gets the displacement of the fixed way.

IV. Control unit is composed of three components (Microcomputer, motor driver, and smoothing circuit). Microcomputer which send the measured value of the displacement sensor to touch panel, receive an output value from touch panel, and output PWM signal. Motor driver amplifies PWM signal. Smoothing circuit smooth PWM signal, and output constant voltage.

4. Process Flow

Figure 8 shows a typical processing flow of the system when a finger touches the touch panel.

I. Determine whether finger touched the touch panel or not.

II. Determine the position of finger touching the screen. Get the displacement of the fixed way from the displacement sensor.

III. After browsing information file to determine the output value from the position and displacement value, send the output value to the control unit.

IV. The control unit receives the output value, and controlling voltage of the solenoid (PWM).

5. Preliminary Experiment

Using the prototype device, we investigate whether reaction force can be actually controlled by solenoid as mentioned in Sect. 2.2. This preliminary experiment confirms about the relation between the reaction force and the electric current flowing through solenoid.

5.1 Reaction force by solenoid using PWM

The voltage supplied to the solenoid is controlled by the PWM. We measure the relation between the reaction force and the electric current flowing through solenoid when changing the duty ratio of PWM. The experimental results are shown in Fig. 9.

Figure 9 shows that as the duty ratio increases the reaction force becomes stronger. That is, the device becomes harder as mentioned in Sect. 2.2. Therefore, hardness can change by duty ratio of PWM.

6. Case Study

For example of the application for our device, we have designed a software keypad that is expected to reduce miss typing. The existing touch panel likes smartphones or tablets shown in Fig. 10 are easy to make mistakes. This is because the existing touch panel is not telling whether the button is pushed exactly or not.

In contrast, our device changes hardness according to the image displayed on screen as follows;

I. The area of button’s image is set soft. It gives a weak hardness when pushing.
II. The area of frame image is hard. It gives a strong hardness when pushing.

This software keypad may reduce the miss ratio of key typing by limiting a pushable region physically by changing hardness. To confirm this effect, we have measured the consumed time for key typing and the number of misses typing by changing hardness and not changing hardness. In addition, we have taken the questionnaire whether subjects can recognize difference in hardness or not. Figure 12 shows a snapshot of the experiment. In this experiment, eleven buttons with different hardness to background image were prepared. There are 6 testees include 5 men and 1 woman. All of these testees are 20s. The experimental results are shown in Fig. 13, and Fig. 14.

Questionnaire asks whether the difference of hardness is recognized or not. We let the testes evaluate this questionnaire at five grades of poor as 1 to excellent as 5. As a result, the average score becomes 4.5.

Compared with the case when the hardness of the image buttons is not changed, our study demonstrates that the input is faster and the ratio of the mistaken key typing can be reduced when the harness is changed. From the results of questionnaire, almost everyone could recognize difference in hardness.

7. Conclusions

In this research, we have proposed a haptic device expressing hardness of the virtual object using solenoid. In the preliminary experiment, we measured the relation between the reaction force and the current for the solenoid used. The result of the preliminary experiment measuring the reaction force on prototype devices shows that it is possible to control reaction force using solenoid. In addition, as an example of the application of this technique, we design a software keypad which can demonstrate the feel of buttons through images on its touch panel. Compared with the case when the hardness of the image buttons is not changed, our study demonstrates that the input is faster and the ratio of the mistaken key typing can be reduced when the harness is changed using our technique. Therefore, our device can realize a haptic device using solenoids, which is not necessary to attach any devices to fingers, the touch panel can be changed and can express hardness just put smartphones or tablets on this device.

As future work, we will develop the application devices such as follows;

1. A touch panel which transmit information in tactile.
2. Electronic advertisements with the touch feeling as same as real products.

3. A portable game player that can be played by tactile.

References


Shenjing Chen (Non-member) was born on March, 1991. He received the B.S. degree in Electrical Engineering from Kyushu Institute of Technology in 2013. He is studying in Graduate School of Engineering, Kyushu Institute of Technology, Japan. His current research interests include sensor application systems, computer vision and image processing.

Yuya Kawahara (Non-member) was born on July, 1989. He received the B.S. degree in Kyushu Institute of Technology in 2012. He is studying in Graduate School of Engineering, Kyushu Institute of Technology, Japan. His current research is sensor application systems.

Akira Yamawaki (Member) was born in Chiba, Japan, on November, 1974. He received M.S. degrees in Electrical Engineering from Kyushu Institute of Technology, Japan in 1999. During 1999-2000, he was a system-on-chip designer of Mitsubishi Electric Corporation. He received Ph.D in Electrical and Electronic Engineering from Kyushu Institute of Technology in 2006. From 2000-2007 he was an assistant in Kyushu Institute of Technology. Since 2007, he has been an Assistant Professor in Kyushu Institute of Technology. His current research interests include computer vision, digital hardware system, smart sensor system, sensor network and reconfigurable hardware system. He is a member of IEICE and IIAE.

Seiichi Serikawa (Member) was born in Kumamoto, Japan, on June, 1961. He received the B.S. and M.S. degrees in Electronic Engineering from Kumamoto University in 1984 and 1986. During 1986-1990, he stayed in Tokyo Electron Company. From 1990 to 1994, he was an assistant in Kyushu Institute of Technology. He received the Ph.D. degree in Electronic Engineering from Kyushu Institute of Technology, in 1994. From 1994 to 2000, he was an assistant Professor at the Kyushu Institute of Technology. From 2000 to 2004, he was an associate Professor at the Kyushu Institute of Technology. Since 2004, he has been a Professor at the Kyushu Institute of Technology. Recently, he is the Dean of Department of Electrical Engineering and Electronics of School of Engineering in Kyushu Institute of Technology. His current research interests include computer vision, sensors, and robotics. He is a member of IIAE, IEEE, and IEICE.