Wearable Stick-Slip Display on Fingertip to Reproduce Rubbing Sensation

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Keywords: Stick-slip display, rubbing sensation, fingertip, wearable

ABSTRACT

We developed a wearable stick-slip display using a rotating cylindrical contactor to reproduce friction sensation during rubbing a material. This paper introduces the mechanism of our device and a method to reproduce sensation of rubbing a silicon rubber or a wood based on the data measured by a force sensor.

1 INTRODUCTION

Various wearable tactile devices for presenting a sensation of rubbing or touching a material have largely developed. Vibration is popularly used for reproducing material texture sensation [1][2]. However, though vibration was found that it affects the friction sensation, it is still difficult to control stick-slip sensation in wide range to increase the realistic sensation of rubbing process. Other studies have developed skin deformation devices to provide reaction force to the finger pad [3][4][5][6]. However, these devices are suitable for stretching the skin only but all of these cannot be used to provide slip sensation continuously because of the limitation of the contactor movement.

Our study aimed to reproduce stick-slip sensation of various materials with a cylindrical contactor that can be rotated and provide stick-slip sensation continuously. We considered that, the friction sensation can be controlled by changing the strength of skin deformation, frequency and amplitude of stick-slip vibration. In this study, we conducted an experiment to investigate the effect of stick-slip vibration of our device on the intensity of friction sensation.

2 WEARABLE STICK-SLIP DISPLAY

Our device is composed of a DC motor, a cylindrical contactor, and a fingertip glove to fix the DC motor to the fingertip (Fig. 1). We used 3D printer to make the contactor and fingertip. The material of these parts was PLA (Polylactic Acid) and lamination pitch of the 3D printer was 0.1 mm. The fingertip glove can be resized according to the size of the finger. The glove is easy to wear, it is lightweight (20g), simple in mechanism and does not disturb the finger's movement. Stick-slip sensation changes depending on the coefficient of dynamic friction between the finger pad and the surface of a material. Most of previous devices cannot control the stick-slip sensation with wide range because the contactor's movement was very limited. In our study, we designed to allows the contactor rotating and slipping on the skin continuously. Our device also can provide wide range frequency of vibration sensation by the DC motor that actuated with alternative current input [6].

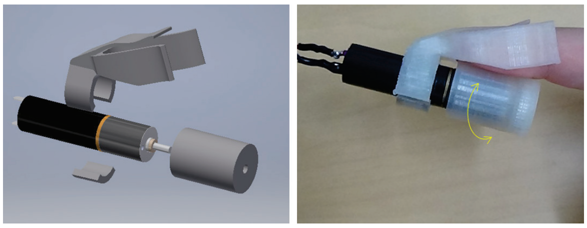

Fig. 1 A design of our wearable stick-slip display (left) and the overview of our display wearing on the index finger (right)

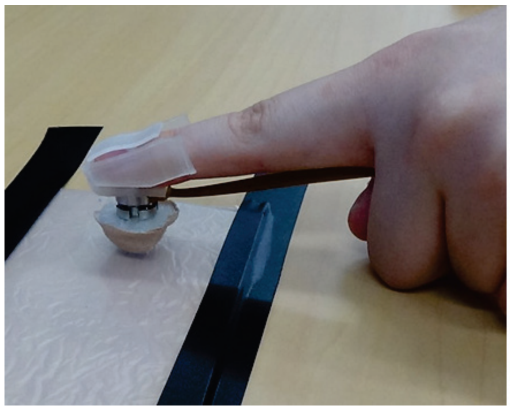

Fig. 2 Force sensor on fingertip for measuring the friction force of a material

3 EXPERIMENT

3.1 Purpose

In this experiment, we investigated the effect of the rotational force that continuously stretch the skin, vibration amplitude and vibration frequency of the contactor on stick-slip sensation. In the beginning of the experiment, we measured the friction force of two materials with different friction coefficient using a force sensor (Fig. 2). Then, we edited the measured waveforms and converted them into the voltages to actuate the contactor.

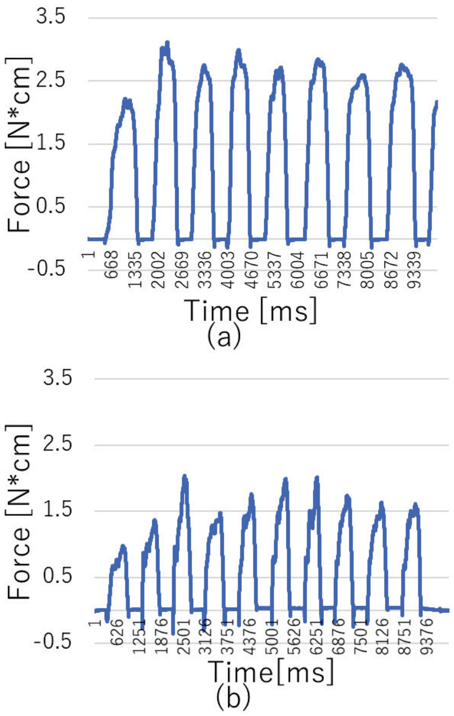

Fig. 3 Dynamic friction force during rubbing a silicon rubber (a), and wooden table (b) by the force sensor

3.2 Method

We measured the dynamic friction force of silicon rubber (friction coefficient of 0.74) and wooden table (friction coefficient of 0.35) with a force sensor (μDynPick, WACOH). Figure 2 shows the overview of the experiment and the force sensor that we used to measure the friction force during rubbing a silicon rubber and a surface of wooden table. Figure 3 shows the result of this measurement. The horizontal axis represents time, and the vertical axis is friction force (the unit was in N*cm because we used torque axis of My direction). The result of measurement showed that, the reaction force during rubbing a silicon rubber is higher than that during rubbing a wooden table. It is due to the friction coefficient between the skin and the silicon rubber is higher than that of the wood. With this result, we did not find the different characteristics (i.e. waveform of stick-slip vibration) between rubber and wood during rubbing process. Therefore, we considered that it is impossible to replay the stick-slip with realistic sensation by only the raw data of force sensor.

In order to replay the stick-slip sensation, we considered a method to edit and convert the dynamic friction force that measured by the force sensor to the voltage waveform to drive the DC motor. In this experiment, we edited the measured data as follow. We increased the amplitude of friction force waveform of the wooden table to the value that was almost the same as the amplitude of

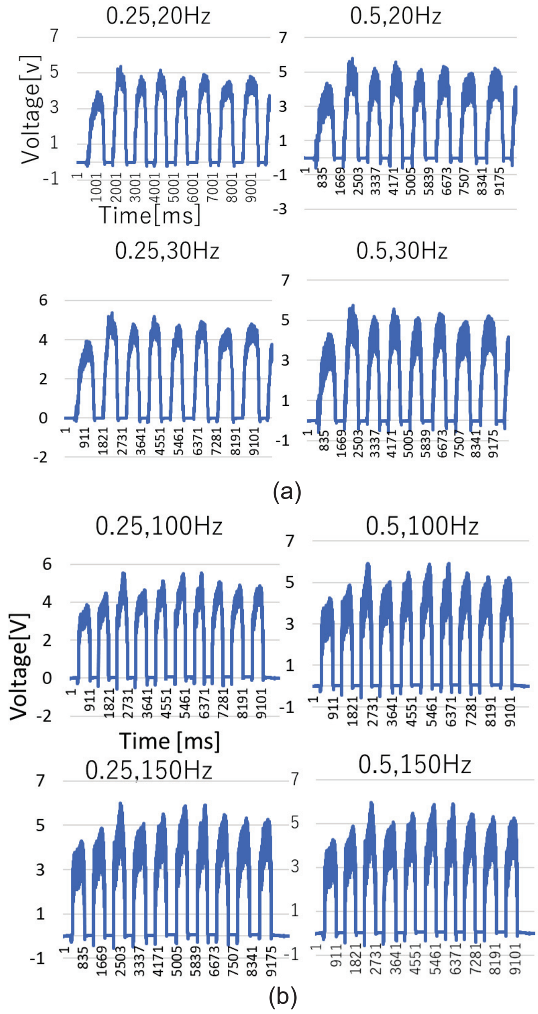

Fig. 4 Eight conditions of waveforms that were edited from the data of rubbing a silicon rubber (a), and wooden table (b) to replay the stick-slip sensation

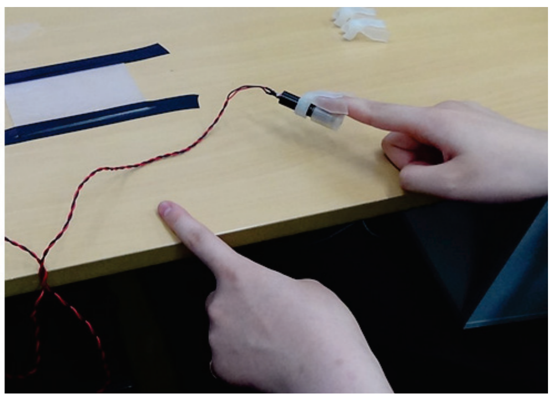

Fig. 5 Overview of the experiment. The stick-slip vibration was presented on the index finger of right hand and participant used the index finger of left hand to rub the real materials for comparison.

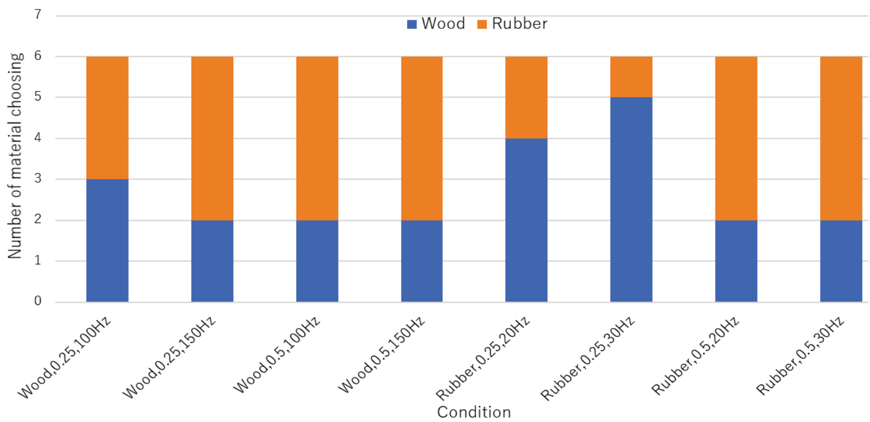

Fig. 6 Experiment result

friction force of the silicon rubber. This allows the contactor slipping on the skin with almost the same rotational force of the contactor. Because we could not observe the stick-slip vibration from the data of the force sensor, we added sine waveform vibration with frequencies of 20 and 30 Hz to the data of silicon rubber and frequencies of 100 and 150 Hz to the data of wood. The amplitudes of vibrations were {0.5 and 0.25} × 1.6 V. Therefore, there were eight conditions. Figure 4 shows the waveforms for replaying stick-slip sensation. The horizontal axis is time, and the vertical axis is the voltage for driving the DC motor.

Six students aged 21-24 participated in this experiment. They were not trained to understand the stimulation of any material before the experiment. There were directly asked to choose the rubber or wood when the stimuli were presented on the index finger of right hand by our stick-slip display. Participants used their index finger of left hand to rub on the surface of rubber or wood to compare the friction sensation between the stimuli by our device and that by the real material (Fig. 5).

3.3 Result and Discussion

Figure 6 shows the result of our experiment. According to the result, most participants chose the stimulation as a rubber rubbing sensation when the vibration amplitude or the frequency was high. In contrasts, they chose the stimulation as a sensation of wooden table rubbing when both vibration amplitude and frequency were low.

It indicated that, both amplitude and frequency of the vibration affect to the stick-slip sensation of the material. The effect of the rotational force was not observed for this experiment. It is because that, the friction force data of wooden table were edited to the strength that were almost the same as that of silicon rubber. Actually, the slippery of wooden table is higher than that of rubber. Therefore, the rotational force of contactor for slip sensation of wooden table need to be higher than that for the rubber. In our further study, we will observe the movement of the contactor and clarify the relationship between rotation (rotational force, vibration amplitude, and frequency of the contactor) and the intensity of stick-slip sensation.

4 CONCLUSIONS

In our study, we developed a wearable tactile device that can provide stick-slip sensation continuously without the limitation of the contactor movement. The result of the experiment showed the necessity of setting the vibration amplitude and vibration frequency in order to present various stick-slip sensations. It indicated that material with high friction can be reproduced by increasing the vibration amplitude or frequency. In our future study, we aim to investigate the effects of contactor rotational speed and vibration pattern to control the friction sensation in a wider range.

ACKNOWLEDGEMENT

This research was supported by JSPS KAKENHI Grant Number JP18H06481, JP19K20325 and Keisya FC411.

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