IMPEDANCE SENSING MECHANISM
FOR A NEW MINIATURE HAPTIC ACTUATOR BASED ON MR FLUIDS

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Abstract: Previously, we successfully developed a new miniature haptic actuator based on MR fluids, designed to convey realistic and various kinaesthetic sensations to users in small electronic devices. The haptic sensation, which is generated in the form of resistive force, should vary according to user's press for demonstrating its real-world haptic application. Thus, a sensing method for gauging the pressed depth by users should be integrated into the proposed actuator. To determine the pressed depth of the MR actuator, this study proposes an impedance sensing mechanism for measuring the impedance change of the solenoid coil embedded in the actuator in the form of voltages to estimate the pressed depth. The sensing capability of the proposed sensing mechanism was evaluated. The results show that the sensitivity of the proposed impedance sensing method is sufficient to regulate the output resistive force over a small stroke range of the actuator.

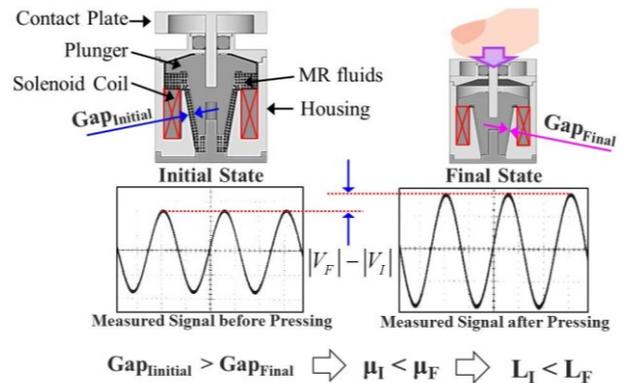**Keywords:** MR Actuator, Impedance Sensing, Haptic, Miniature.

1. INTRODUCTION

Generally, users rub (tactile) and press (kinaesthetic) target objects when they try to perceive those objects. Therefore, to convey a more realistic and vivid haptic sensation, both kinaesthetic and tactile information should be presented to users. While miniature tactile actuators have been widely researched, only a few kinaesthetic devices have been studied [2,3] Most of the kinaesthetic devices proposed so far have adopted commercial AC/DC motors to generate various kinaesthetic sensations. [4-7] Since the kinaesthetic devices use AC/DC motor, they are difficult to be embedded into small electronic products due to their size. Moreover, actively controlled motors are prone to instability problems, which can be a significant road block for certain applications. [8] Therefore, we developed a new miniature MR actuator to overcome the limitations of conventional actuators. [9] In developing the miniature MR actuator, MR fluids were adopted because the controllable fluids not only allow the proposed actuator to create various and strong kinaesthetic sensations, but also enable it to avoid any stability problems.

In order to present haptic applications by using the proposed miniature MR actuator, the haptic sensation in the form of resistive force should vary according to the user's press. Hence, this paper proposes new impedance sensing mechanism coupled with actuating function. This impedance sensing method gauges the pressed depth while the actuator generates resistive force to users. The proposed sensing method can help the developed actuator to be applied to real-world haptic application without extra sensors.

2. A MINIATURE MR ACTUATOR WITH IMPEDANCE SENSING MECHANISM

A schematic view of the miniature MR actuator is shown in Figure 1. The housing contains the solenoid, the plunger, and the MR fluids. The solenoid coil is attached on the bottom of the housing, and the cone-shaped plunger is placed inside the solenoid coil. The contact plate is fixed to the upside of the plunger. Since the housing and the cone-shaped plunger are constructed by a ferromagnetic material, those parts guide magnetic fields generated from the solenoid coil. The housing contains MR fluids, and the MR fluids flows through the gaps between the housing and the plunger. When the electric current is applied into the solenoid coil, strong electro-magnetic field is created in the gap. This magnetic field increases the viscosity of MR fluids in the gap, and its viscosity change creates strong resistive force against user's pressing force.
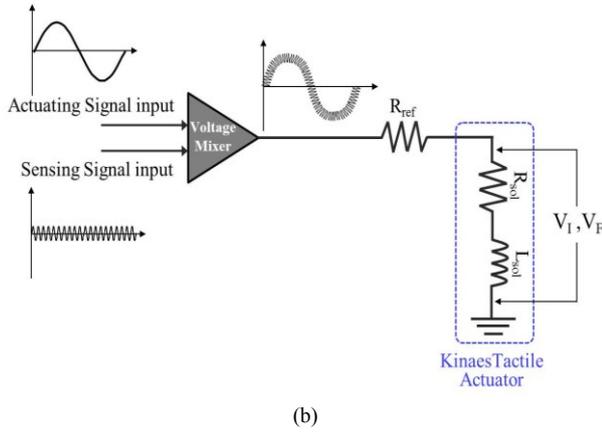

(a)

(b)

Figure 1. Impedance sensing mechanism for measuring user's pressed depth of MR actuator: (a) Impedance sensing mechanism, (b) System model

In order to demonstrate a real-world haptic application with the proposed actuator, a control system with efficient actuating and sensing method should be designed. In other words, to control the output actuation force of the MR actuator based on input motions, a sensing scheme was integrated into the developed actuator. Hence, to measure the pressed depth of the MR actuator, the impedance change of the solenoid coil in the actuator was measured in the form of voltage as shown in Figure 1(a). When a user presses the contact plate of the proposed actuator, the gap between the plunger and the housing become reduced. The decrease of the gap causes to increase the magnetic permeability of the actuator, and this increases the inductance of the solenoid coil in the actuator. The increase of the inductance raises the output voltage as shown in Figure 1(a). An alternating current with frequency 'ω' is applied to the solenoid coil for creating varying magnetic field. The proposed sensing method can be modelled as shown in Figure 1(b). To realize actuating and sensing simultaneously with the proposed actuator, we used mixed signals, which have a low frequency signal for actuating and a high frequency with small amplitude for sensing. After the mixed signal passes through a reference resistor, it actuates the proposed actuator. The sensing signal is measured at a point between the reference resistance and the solenoid coil. The changes of peak voltage are gauged to estimate the pressed depth. The magnitude of the sensing signal due to inductance changes is given by following Equation (1). Output voltage is a function of frequency and inductance.

$$\left|V_{Output}\right| = \frac{\sqrt{R_{Sol}^2 + (\omega L_{Sol})^2}}{\sqrt{(R_{ref} + R_{Sol})^2 + (\omega L_{Sol})^2}}\left|V_{Source}\right| \tag{1}$$

Reference Resistance	:	$R_{ref} = 12\Omega$
Actuator Resistance	:	$R_{Sol} = 14\Omega$
Sine Wave Frequency for varying Magnetic Field	:	$\omega\ (from\ 100Hz\ to\ 500Hz)$
Sine Wave Magnitude for varying Magnetic Field	:	$V_{Source} = 3.3V$
Inductance of Solenoid	:	$L = \dfrac{\mu N^2 A}{\ell}$

4. CONCLUSION

This paper has presented a new impedance sensing method combined by actuating function of the miniature MR actuator. To realize actuating and sensing simultaneously with the proposed actuator, this paper proposed to use mixed signals, which have a low frequency signal for actuating and a high frequency with small amplitude for sensing. The magnitude of the sensing signal due to impedance changes was gauged to estimate the users' pressed depth. The gauged voltage signal ranges from 0.4V to 4V according to the pressed depth over a range of 0~1.4mm with sine wave input of 300Hz. The sensitivity of the proposed impedance sensing method is enough to regulate the output resistive force over a small stroke range.

In summary, this study has proposed a new method for gauging the stroke of the miniature MR actuator. The proposed impedance sensing method paved the way for the miniature MR actuator to be applied real-world haptic application such as game interface, mobile phone, and etc.

5. ACKNOWLEDGEMENT

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