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Design of New Micro Actuator for Tactile Display

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Abstract: In order to provide the realistic tactile sensation in a pin-array tactile display for a hand-held device, we need to consider the pins' gap, the pins' stroke, the output force, and the working frequency of the tactile display. This paper presents a new small-scale actuator with a solenoid, a permanent magnet, and a elastic spring for a tactile display. The feedback force of this actuator is generated by the interaction among a solenoid, a permanent magnet, and a elastic spring. We separate the elastic springs into several elastic plates in order to considerately minimize the pins' gap of tactile display without decreasing the pins' stroke, the output force, and the working frequency of the displays. In the proposed tactile actuator, a micro-pin is actuated to satisfy the above specification (the pins' gap, the output force, and the working frequency). Hence, a tactile display with the proposed tactile actuators provides realistic cutaneous sensation to human operators.

1. INTRODUCTION

While visual information is the most dominant sensory input for perceiving an object, haptic information coupled with the visual information increases the sense for the real. Especially, in hand-held devices, haptic feedback is regarded as one of the dominant factors for reality or immersion because the size of a visual display unit is not enough to provide realistic feeling to users. A user can interact with a hand-held device efficiently by adding haptic information to auditory and visual information.

For reach and efficient interaction, there have been fruitful research works on using a vibration motor because an eccentric motor was already applied in many commercial hand-held devices. A. Chang et al.(2002) developed a mobile system for providing vibrotactile information coupled with auditory information called the ComTouch. The ComTouch allows rich communication between users by converting hand pressure into vibrational intensity. I. Oakley et al.(2005) developed a hardware platform with motion sensing input and vibrotactile output, which was applied to the specific scenario of scrolling. They described the methods by which movement, in the form of tilting, can be used to control scroll position, and by which a dynamic vibration signal can be used to present information relating to a scrolling operation. Immersion cooperation (2006) developed the VibTonz® system that increases the quality of the communication using vibration.

However, the use of the eccentric motor limits our ability to discriminate diverse vibrotactile sensation. In order to provide diverse tactile feedback, researchers focused on developing and studying haptic actuators which can generate vibrotactile information having a large bandwidth. I. Poupyrev et al.(2002) has been trying one piezo-actuator to be embedded in mobile electrical devices. This haptic actuator can convey the feeling such as clicking a button, surfing menus and etc. A. Yamamoto et al.(2006) presented an electrostatic tactile display which consists of a thin conductive film slider with stator electrodes. T. Nara et al.(2001) used surface acoustic waves(SAWs) created by inter-digital transducers to modulate the amount of surface friction applied to a slider with steel balls. These tactile systems can express friction between the finger pad and the surface of an object. However, it is not easy to directly stimulate the mechanoreceptors according to the surface property of the object with these systems.

For carrying various and realistic tactile sensation to a human operator, a bundle of mechanical actuators were used. Y. Makino et al.(2004) suggested a large-area tactile display actuated by suction pressure based on the tactile illusion. L. Winfield et al.(2007) used piezoelectric crystal stack to build the tactile display which can generate various textures with ultrasonically vibrating plate. M. Konyo et al.(2005) proposed a ciliary device which allows human operators to delicately manipulate target object. In their research, soft high polymer gel actuators are used for delicate touching. The slope structure of the cilia produces vibratory stimuli tapping and stroking on the skin surface depending on frequency of driving voltage. M. Hafez and M. B. Khoudja(2005) suggested electromagnet tactile display that consists of flexible magnetic membrane and magnetic coils on a multilayer PCB. In these tactile displays, it is hard to display a detail texture and/or a small-scale shape. In order to

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overcome those limitations, there have been attempt to develop pin-array type tactile actuating systems which are the prominent stimulating method for human's mechanoreceptors.

Q. Wang and V. Hayward(2006) developed a pin-array type tactile transducer system which can generate a relatively large lateral skin deformation by adjusting the cantilever mechanics. R.Velazquez et al.(2005) presented a tactile actuating system with SMA (shape memory alloy) coil and permanent magnet. I. R. Summers and C. M. Chanter(2002) used piezoelectric bimorphs as the skin contactor. S.Y. Kim et al.(2007) developed a compact pin-array type of tactile display unit and attached it to a PHANToMTM haptic device. Moreover, they presented area-based haptic rendering method to provide the kinesthetic force and the tactile sensation to human operators. However, it is not suitable for applying them to a hand-held device because of the size.

For hand-held devices, tactile actuators have to be designed with consideration of the pin's gap, the output force, and the working frequency. In this paper, we present the design of a new micro-tactile actuator for hand-held devices. The proposed tactile actuating system can minimize the pins' gap, can adjust the working frequency, and can stimulate the skin with output force.

2. DESIGN OF NEW ACTUATING MODULE

We selected a solenoid type actuator for tactile actuation because it is easily controllable, creates enough force to stimulate a user's skin, and generates high frequency. Furthermore, the solenoid type actuator is simply miniaturized, and consumes comparably low power. Until now, there were various attempts to develop a pin-array tactile display with a solenoid actuator (S. F. FRISKEN-GIBSON et al.,1987; T. Fukuda et al., 1997; M. B. Khoudja et al., 2004). However, the actuating force of a solenoid depends on its diameter considerably, so the conventional pin-array tactile display using solenoids has a poor spatial resolution. In order to increase spatial resolution, we developed a micro push-pull type solenoid with a spring. The proposed push-pull type solenoid consists of a steel core with a coil and a permanent magnet to minimize its diameter as shown in Fig. 1.

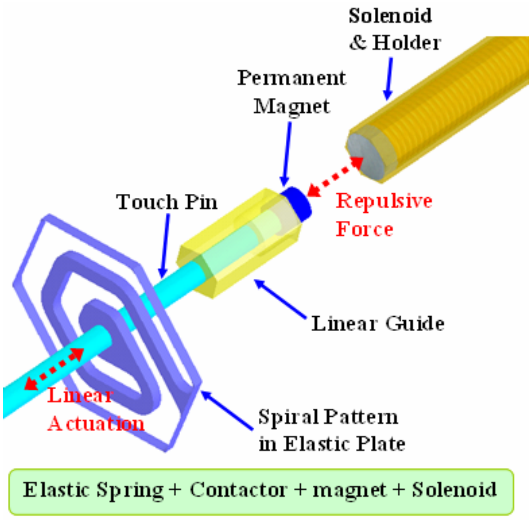
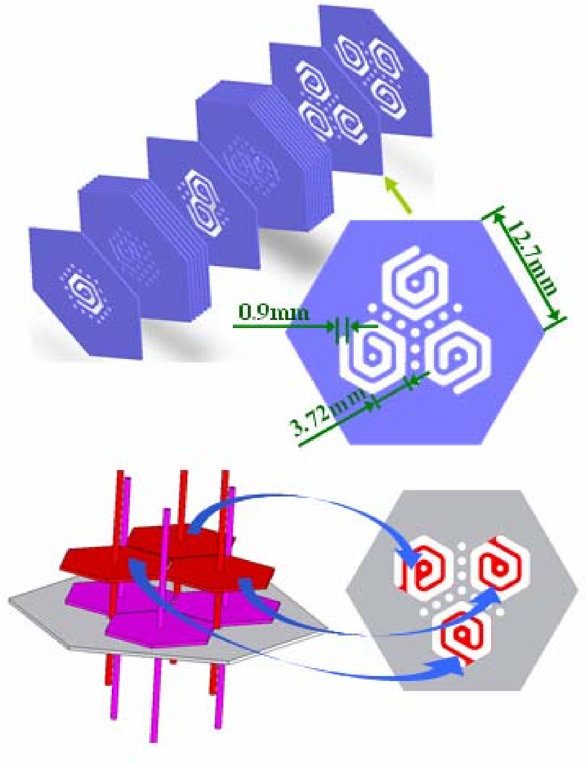


Fig. 1. Design of New Actuating Module

The contactor is attached on the magnet and it is fixed in the center of the spiral pattern. This spiral pattern plays a role in elastic spring. The conventional push-pull type solenoid generates not enough force to stimulate human skin due to the small diameter. However, the spiral pattern in the proposed actuator generates additional feedback force to stimulate the humans' mechanoreceptor.



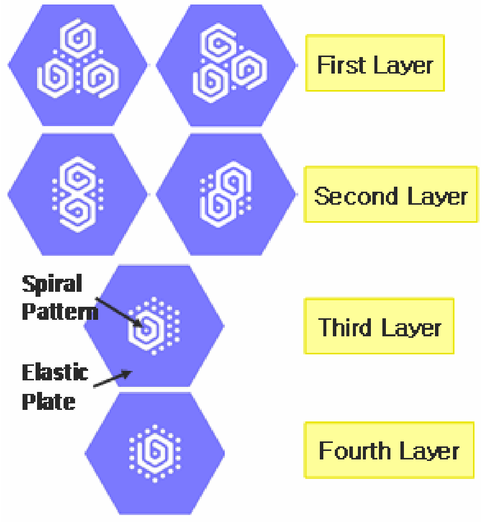


Fig. 2. Multilayer Elastic Plate with different Spiral Patterns

In designing the spiral pattern, we have to increase the width of the patterns because the width is proportional to the stimulating force and the stroke. The width of the spiral patterns can be maximized separating the patterns into multilayer elastic plates in a limited place. Therefore, we proposed a new actuation system based on multilayer plates with different spiral patterns as shown in Fig. 2. The shape of each spiral pattern was decided as a rounded hexagon for spatial efficiency as shown in Fig. 3. The minimum gap of the hexagonal spiral patterns is 0.9mm and the side of the hexagonal spiral pattern is 3.72mm. We designed six kinds of elastic plates for actuating 37 pins. In the first layer, three spiral patterns which grasp outer pins are differently located in two kinds of elastic plates. These elastic plates with three spiral patterns are rotated and settled. In the second layer, two spiral patterns which grasp one step inner pins are differently located in two kinds of elastic plates. In the third layer, one spiral pattern which grasps two step inner pin is located. In the third layer, one spiral pattern which grasps three step inner pin is located.

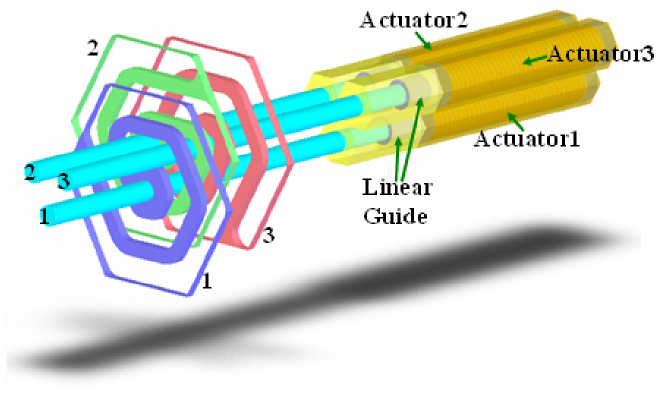


Fig.3 Assembled Tactile Units

Fig. 3 shows the assembling procedure using three actuators. One actuator unit consists of an elastic spring, a contactor, a permanent magnet and a solenoid. The contactor is grasped to the elastic spring. The permanent magnet is attached to the contactor and it interacts with the corresponding solenoid. The contactor1 moves up and down passing through spaces of the elastic spring 2 and 3. The contactor2 moves up and down passing through spaces of the elastic spring 1 and 3. The contactor3 moves up and down passing through spaces of the elastic spring 1 and 2. Likewise, the contactor passes through the spaces of other elastic springs. This assembling method can minimize the contactors' gap without decreasing the stimulating force and working amplitude of the large spiral patterns in the multilayer elastic plates. The contactors move up and down by repulsive force between permanent magnets and magnetized solenoids. During the actuation, contactors cannot move up or down in a straight line. To compensate the movement, we added the linear guide to the actuation system as shown in Fig. 3.

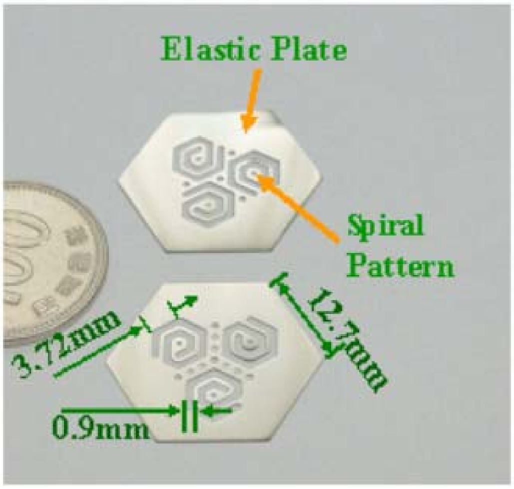


Fig. 4. Design of New Actuating Module Elastic Plate with Spiral Patterns

The elastic plates were manufactured by commonly used machine work, the wire cutting as shown in Fig. 4. The wire cutting provides a thick metal spiral pattern.. As the width of the spiral patterns become larger, the patterns become thicker growing the feedback force and working amplitude.

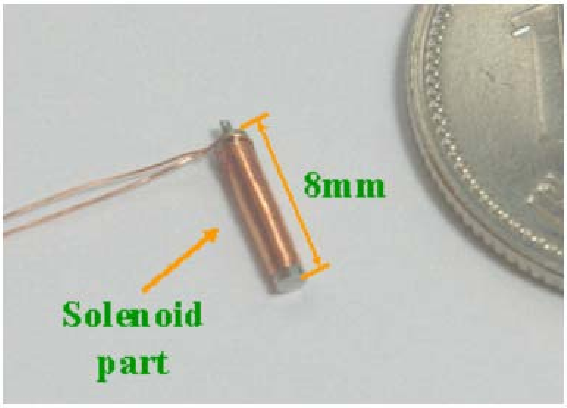


Fig.5 Micro-mini Solenoid

For actuation component, we manufactured the micro-mini solenoid whose diameter is 1.5mm as shown in Fig.5. Due to the small gap between the permanent magnet and the solenoid, there can be exist interference in the proposed actuation system. Therefore, the linear guide is extended to the permanent magnets (Fig. 1).

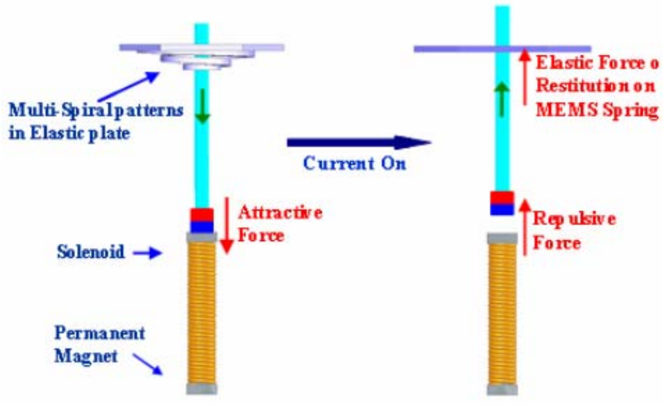


Fig. 6 Basic driving principle of a new actuator

Fig. 6 shows the driving principle of the proposed actuator for the tactile display. Since the core of the solenoid is made by a steel alloy, the permanent magnet attached to the contactor is attracted to the core with stretching the spiral pattern on an initial state. When the solenoid becomes magnetized with electricity, returning actuation is generated by the force of restitution due to the interaction between the magnetized solenoid and permanent magnet. Finally, the end point of the contactor stimulates a human operator's finger pad.

3. NEWLY TACTILE DISPLAY WITH THE PROPOSED ACTUATOR

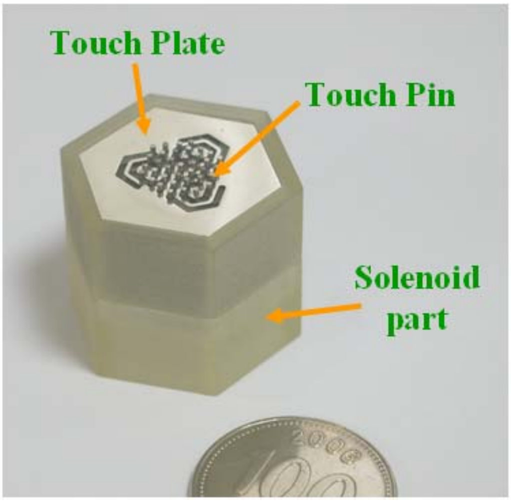


Fig. 7 A New Tactile Display with the Proposed Actuator

Fig. 7 shows a new tactile display with the proposed tactile actuators. The height of the tactile display is 24mm and a side of hexagon is 14mm. The thirty seven actuators are independently moved to stimulate an operator's finger pad. The pin spacing is 1.5mm and the diameter of each pin is 0.5 mm. Each actuator generates a stroke larger than 0.2mm and has a low operating input voltage (10V). In addition, the proposed actuator's response time is on the order of millisecond and it can generate force up to 0.06N.

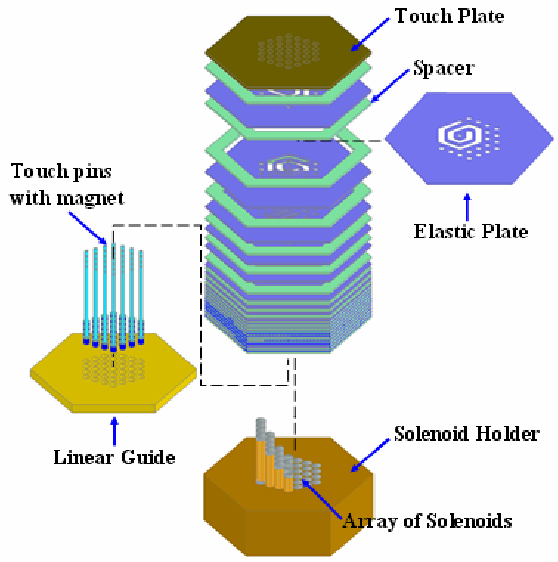


Fig. 8 Disassembled Figure of Tactile Display

Fig. 8 shows the disassembled structure of the tactile display with the proposed actuators. The new tactile display consists of a touch plate, 18 elastic springs, 18 spacers, 37 contactors with magnets, a linear guide and the array of solenoids and a solenoid holder. The touch plate was covering the elastic plates. The elastic plates with the different spiral patterns were piled minimizing contactors' gap. The spacers were inserted among each elastic plate. The contactors with permanent magnets at the end of pins were assembled to the hole of the spiral patterns in the elastic plates. The linear guide causes vertically straight actuation of the contactors. The array of the solenoids is grasped by the solenoid holder and they generate repulsive force by the interaction with the permanent magnets.

We measured the amplitude of the proposed tactile actuator as a function of vibration frequency to gauge the bandwidth of the actuator which generates the amplitude much more than vibrotactile threshold of human's finger pad. Fig. 9 shows a schematic diagram of the measurement system. The amplitude of developed tactile actuator was measured with the LDV Laser Vibrometer.

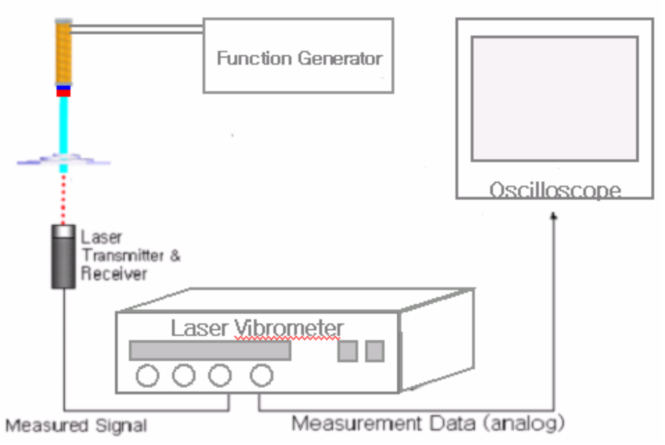


Fig. 9 Measurement System

The square wave from a function generator was flowed into the tactile actuator. We used a laser vibrometer to measure the amplitude of the actuator depending on the frequency. The measured amplitude by laser vibrometer is displayed in an oscilloscope. Fig. 10 shows the result of the amplitude of the tactile actuator. In order to compare the amplitude of the tactile actuator with vibrotactile thresholds, we depicted the vibrotactile thresholds which measured (K.U. Kyung et al., 2005). The stroke of the proposed tactile actuator is much higher than humans' vibrotactile thresholds in the range of 0 to 500Hz. Especially, the maximum stroke of the proposed tactile actuator is almost same in the frequency region below 360Hz. Therefore, the proposed tactile actuator can stimulate the human's mechanoreceptors (Meissner corpuscle, Merkel's disk, Ruffini ending, and Pacinian corpuscle)

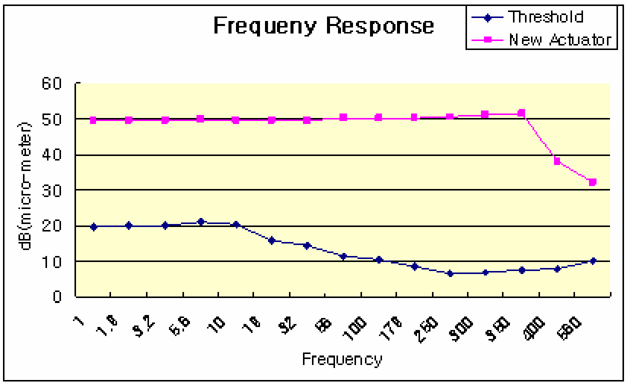


Fig. 10 Frequency Response of New Actuator

4. CONCLUSION

A pin-array type of tactile display is an effective way to provide a realistic tactile sensation to a human operator. For a realistic tactile sensation, the gap between neighbor tactors should be smaller than the two point discrimination threshold. Even though the pin-array type is a powerful structure for a tactile display, it is not easy to apply it to the hand-held device. This paper proposed a micro-pin actuator which provides powerful mechanism generating high working frequency and amplitude in micro-size using the elastic returning and magnetic force for a hand-held device. This actuator consists of an elastic spring, a contactor, a permanent magnet and a solenoid. The contactor is grasped to the elastic spring which provides the force of restitution. The permanent magnet is attached to the contactor and it interacts with the corresponding solenoid. This micro-pin actuator satisfies the specifications of pins' gap, pins' stroke, output force, and working frequency for displaying tactile sensation. This new type of actuating module offers the possibility to make a compact pin-array tactile display with less than 1.3mm gaps to provide realistic tactile sensation.

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