A Linearvibrotactile Actuator for Mobile Devices

Sang-Youn Kim[1], Bonggoo Kim[2] and Tae-Heon Yang[3]
[1]*Interaction Lab., Advanced Technology Research Center, Korea University of Technology and Education (KoreaTech), (330-708) 1600 Chungjeolno, Byeongchunmyun, Chungnam, Cheonan, Korea*
[2]*R&D Center, Yeonhab Precision Co. Ltd, (330-844)219-27 Haksusosa-gil, Mokcheon-eup, Chungnam, Cheonan, Korea*
[3]*Korea Research Institute of Standards and Science, Daejeon, Korea*

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Abstract: Although, the current vibrotactile actuators are widely used for haptic interaction with mobile devices, they have still problems to be solved before accepting in many mobile devices. The most critical problem is that the conventional vibrotactile actuators creates vibrotactile signal with limited frequency bandwidth. The vibrotactile actuator with large frequency bandwidth allows a user to delicately and immersively manipulate mobile devices. This paper presents a new vibrotactile actuator which creates vibrotactile signals with a large frequency bandwidth. In our actuators, vibrotactile signal is generated by interaction between solenoids and a permanent magnet. Experiments are conducted to investigate whether the proposed actuator generates enough output force to stimulate human skin across a large frequency bandwidth. The result of the experiments demonstrates that the proposed actuator is suitable for the haptic interaction with mobile devices.

1 INTRODUCTION

Recently, the mobile industry is experiencing rapid growth. As computer graphics, multi-media, and 3D sound technologies are incorporated into the mobile device, the devices are expected to be smarter and smarter. According to Microsoft, 4 billion mobile phones are in use all around the world (Microsoft Tag, 2012). A market share of smart phones, which is 25% in 2012, will balloon to 54% (IHS iSuppli, 2012). Due to the smart phones, the function of a mobile phone has shifted from a traditional telephone to an entertainment device with which a user enjoys internet, movies, games, and etc.

Since visual information is most important factor in interacting with mobile devices, mechanical keypads and buttons in mobile devices are being replaced by touch screens to maximize the display area. A touch screen without a mechanical keypad has led to a native user interface (UI) which reduces the learning curve of a user to adapt usage of an application. Enlarged screens and native UI allow a user to intuitive and immersive interaction with mobile devices. However, it is not easy to increase the level of the immersion to the level where users are truly "immersive". To increase the level of the immersion, many researchers and developers focused on creating haptic feedback. The reason is that interaction based touch is first way, and it allows a user to non-verbally and cognitively interact with devices. Therefore, haptic information coupled with visual and/or audio information enables a user to inattentively interact with devices.

Haptic feeling consists of tactile sensation (sensory information acquired by pressure receptors in the skin) and kinesthetic sensation (sensory data obtained by receptors in joints, muscles, and ligaments). Many haptic actuators that directly provide kinesthetic force or pressure are too bulky to be inserted them into mobile phones. Therefore, for creating haptic feeling in mobile devices, many researchers focused on tactile actuators because the tactile actuators can easily be constructed in small size. Among others, vibrotactile actuators have been most widely studied to reproduce haptic sensations on mobile screens by generating short vibration feedbacks, and they have been successfully commercialized in many mobile devices.

There are four major mechanoreceptors (Meissner corpuscle, Merkel's disk, Ruffini ending, and Pacinian corpuscle) in the human glabrous skin and their operating frequency are different from each other except Ruffini ending (Johansson and Vallbo,

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1979); (Johnson et al., 2000.). An eccentric motor, which is the first commercialized vibrotactile actuator, can create operating frequency in the range of 80 to 250Hz. However it is not easy to generate a variety of vibrotactile senation because the eccentric motor creates concentrated force which is in proportional to the square of the number of the motor's revolution. Another problem is that the eccentric motor's response time is too late to be used for conveying vibrotactile sensation to a user in real time. Therefore, a linear resonance actuator (LRA) (Kweon et al., 2008) is developed to improve the response time of the conventional vibrotactile actuators. The LRA creates vibrotactile sensation using resonant effect and its response time is fast enough to be used for vibrotactile actuator. However the strategy of vibration near the resonant frequency limits frequency bandwidth of haptic actuators. Piezo ceramic actuators have been developed for producing vibrations with a wide frequency range from a small device (Poupyrev et al., 2002); (Wagner et al., 2005); (Cruz and Grant, 2011); (Lylykangas et al., 2011). Even though a piezo actuator can have possibility to selectively stimulate mechanoreceptors, its vibrational force is not strong enough to stimulate mechanoreceptors except at their resonant frequencies.

Therefore, in this paper, we propose a linear type vibrotactile actuator which not only creates generates vibrations over a large frequency bandwidth but also generate strong haptic effect sufficient to stimulate human skin.

2 CONCEPTUAL DESIGN AND IMPLEMENTATION

In this section, we describe a proposed vibrotactile linear actuator consisting of a steel housing, a steel flux path, steel ball bearings, two solenoid coils fixed in a steel housing, two permanent magnets passing in and out of the solenoid coils, and a link bar that connects the two permanent magnets. The steel flux path concentrates the magnetic field strength in the gap between the steel flux path and the steel housing. The steel ball bearings decrease friction between the steel housing and the steel flux path. Silicon was attached to both sides of the solenoid coils to minimize the noise from collisions. Fig. 1 shows the component of the proposed actuator and its conceptual design.

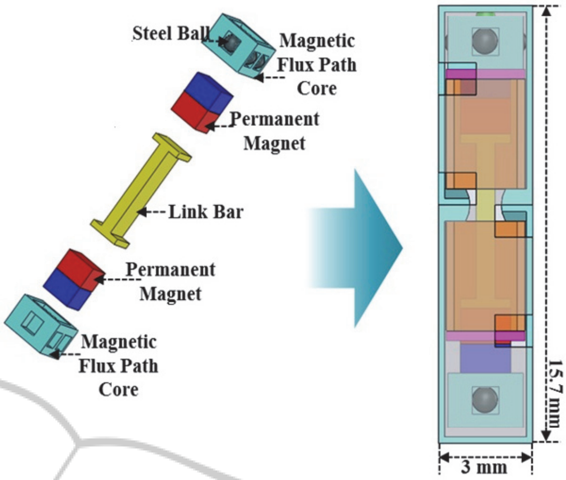


Figure 1: Components of the proposed actuator and its conceptual design.

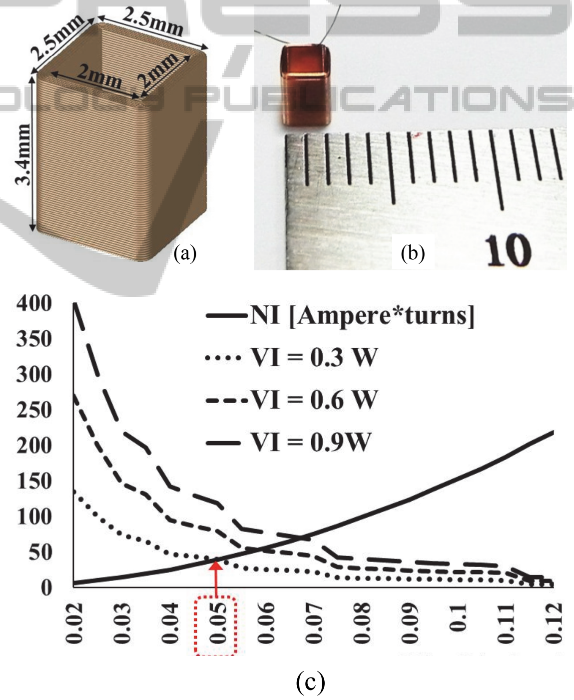
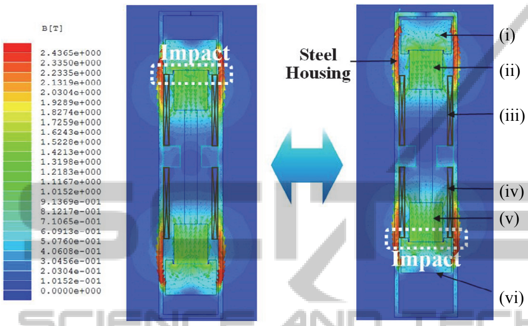


Figure 2: Parametric design of solenoid coil and its picture

In order to maximize the force of an actuator with limited size, we conducted a parametric design for a solenoid. Fig. 2(a) shows the parametric design of the solenoid coil. The size of the solenoid coil was determined by considering the size of the housing and the permanent magnets. The inner width and length of the solenoid coil was determined to be 2 mm × 2 mm, and the outer width and length was chosen as 2.5 mm × 2.5 mm. The height of the coil was chosen as 3.4 mm. For this given size of the solenoid coil, the magneto-motive force (A • turns) generated from the coil was simulated by changing the wire diameter of the coil as shown in Fig.2 (b). The wire diameter of the solenoid coil and the number of turns needed to produce the desired magneto-motive force (A • turns) were determined to be 0.05 mm and 40 A•turns respectively (Fig. 2). The chosen magneto-motive force (40 A • turns) was applied in the FEM simulation to obtain the output force of the actuator. Fig. 2(c) shows the fabricated solenoid coil.



(i) : Upper Steel Flux Path, (ii) : Upper Permanent Magnet,
(iii) : Upper Solenoid Coil, (iv) : Lower Solenoid Coil,
(v) : Lower Permanent Magnet, (vi) : Lower Steel Flux Path

Figure 3: Working principle with FEM simulation of a new impact actuator.

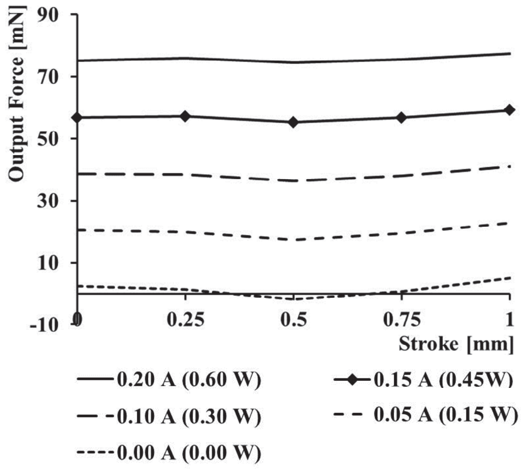


Figure 4: Result for FEM simulation.

Fig. 3 shows the working principle of the proposed actuator and the simulation result when the magneto-motive force of 40 A•turns was provided to the two solenoid coils. The magnetic field from the upper permanent magnet goes by the upper steel flux path and then passes through the steel housing. After that, the magnetic field returns to its original position. Both permanent magnets can be moved up and down according to the direction of the applied current. In order to create a strong impact at the downside of the proposed actuator, the upper and lower permanent magnets are both pulled down by the upper and lower solenoid coils, respectively. For generating a strong impact at the upside, the two permanent magnets are pushed up by the respective solenoid coils. In this manner, repulsive and attractive forces are created by the Lorentz force between the permanent magnets and the solenoid coils. The two permanent magnets and the solenoid coils produce a linear Lorentz force according to the direction of the stroke.

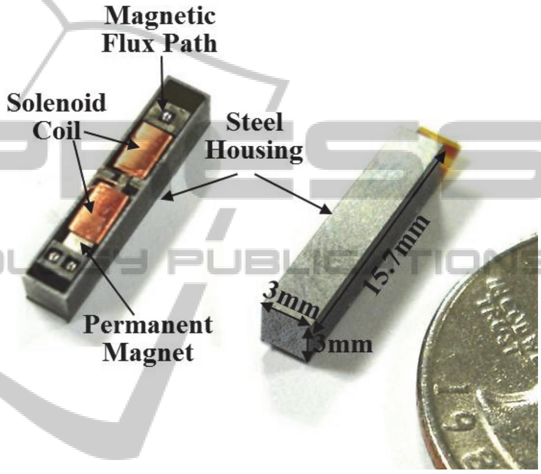


Figure 5: The developed actuator.

The vibrational impact force was 76mN when a current input of 0.2 A is supplied to the actuator. When there is no current input to the proposed actuator, output force becomes 1.5mN which is lower than absolute threshold (Lederman, 1997; Katz, 1989).

Fig. 5 shows the constructed actuator prototype. The solenoid diameter is 2.5 mm and its height is 3.4 mm. The two permanent magnets are installed at the ends of the link bar with their north poles facing each other. The two steel flux paths are mounted at the outside ends of the corresponding permanent magnets. The moving part travels linearly inside the two solenoid coils due to the Lorentz force. The two solenoid coils and the moving part are located inside the steel housing that has two covers (the upper and lower covers). When current is applied to the solenoids, the permanent magnet moves from the initial position to the other end and collides with a silicon bumper attached to the end of the solenoid coils. This collision generates strong and sharp impact vibration. The size of the developed impact vibration actuator is 3 mm × 3 mm × 15.7 mm.

Since the volume of the proposed actuator ($141.3mm^3$) is smaller than that of commercial linear resonance actuators ($360\ mm^3$), the proposed actuator can be easily embedded in mobile devices.

3 CONCLUSIONS

In this paper, we presented a tiny vibrotactile actuator, which is easily embedded into mobile devices, consisting of the moving part, two solenoids, a steel housing, and two covers. Since the proposed actuator provides enough working frequency and output force to stimulate human skin, it can selectively stimulate human's mechanoreceptors. According to the current input, the moving part runs from the initial position to the other end and collides with a silicon bumper attached to the end of the solenoid coils in order to generate vibration. Our work underscores the importance of the proposed haptic actuator to enable users to experience immersion while interacting with mobile devices.

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