Presenting Directional Information on a Mobile Device Using Vibrotactile Flow

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ABSTRACT
In this position paper, we introduce recent research results on creating "vibrotactile flow" on a mobile device using a small number of vibration actuators. Vibrotactile flow is one type of tactile apparent motions, and refers to a perceptual phenomenon where vibration stimulation position is perceived to be moving from one end to the other end. We recently discovered that vibrotactile flow can be robustly created on a mobile device using only two common commercial vibration actuators. By nature, vibrotactile flow is an excellent candidate for direction and navigation cueing. We present the summary of our recent findings regarding vibrotactile flow on a mobile device and discuss further research issues.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: Haptic I/O

General Terms
Algorithms, Design, Experimentation, Human Factors

Keywords
Vibortactile flow, mobile device, tactile apparent motion, direction, navigation, information delivery

1. INTRODUCTION
The past ten years observed the enormous growth of the mobile device market. As such, diverse new functions have been converged into mobile devices, along with novel and convenient user interfaces. However, the sensory information that a mobile device can provide is inevitably limited due to its size requirement. To improve the situation, vibrotactile feedback has been actively employed for alternative sensory information. But it is currently underutilized for many reasons, such as the inclusion of only one vibration actuator, the lack of high performance miniature vibration actuator, the poor human sensitivity of vibrotaction compared to those of vision and audition, and the insufficient contents and applications that make use of vibrotactile feedback in direct, intuitive, and easy-to-learn manners.

In this position paper, we discuss the feasibility of improving the usability of vibrotactile feedback in mobile devices by using multiple vibration actuators. In particular, we focus on the creation and perception of vibrotactile flow, and its implications to the delivery of directional information when a user holds a mobile device in the hand. The concept of vibrotactile flow is illustrated in Figure 1, which shows a handheld device with two common commercial vibration actuators such as ERM (Eccentric Rotating Mass) or LRA (Linear Resonant Actuator). By controlling the time gap between the vibration activation times of the two actuators or the relatively vibration amplitudes of the two actuators, we can create the sensation that vibration position moves from one end to the other end. This is similar to the concept of tactile apparent motion, which has been well documented in the haptic perception literature. The difference is that in our setup, vibrations are superimposed along the common rigid medium connecting the two vibration actuators, whereas in typical situations of tactile apparent motion two contact sites are isolated and directly stimulated by separate actuators. Recently, we found that the human perception of vibrotactile flow is highly apparent, robust, and repeatable, which allows vibrotactile flow to be an effective method for information transmission in mobile devices. In particular, the spatial nature of vibrotactile flow makes it an excellent candidate for directional information cueing.

In the rest of this paper, we introduce two algorithms for vibrotactile flow rendering in Sections 2 and 3, respectively, describe some applications that we developed in Section 4, and discuss further research issues in Section 5, followed by conclusions in Section 6.

2. TIME INHIBITION
Vibrotactile flow is a vibration wave which originates from one point and gradually propagates to another point. Algorithms for vibrotactile flow rendering on a mobile device can be classified to those using time inhibition and amplitude inhibition, following the terms coined in the early literature on tactile apparent motions or "phantom sensations" [1]. Because of the limited space, we only describe underlying ideas for the algorithms in this and next sections, and refer to our previous publications for further details.

To generate vibrotactile flow, two or more vibration actuators are used. By activating the actuators at different times and superimposing two resulting vibration waves, we can synthesize a new vibration, as depicted in Figure 2. As a consequence, a new wave

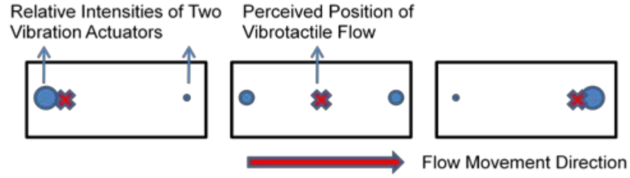

Figure 1: Concept of vibrotacile flow on a mobile device.

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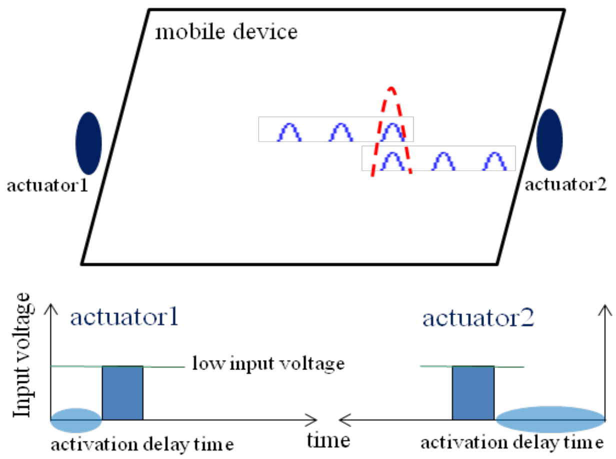

Figure 2: Concept for vibrotactile flow generation with time inhibition.

that has greater magnitude at a target position can be constructed. The target position can be controlled by adjusting the activation delay times of the two actuators, as illustrated in the bottom panel of Figure 2. A user perceives much stronger vibration at the target position. If we move the synthesized position over time, the user perceives vibrotactile flow traveling on the device surface. See [2][3] for the complete algorithm of vibrotactile flow using time inhibition. We confirmed that this algorithm is applicable to both ERMs and LRAs.

3. AMPLITUDE INHIBITION

The other approach for producing vibrotactile flows is to control the relative amplitudes of vibration actuators. For instance, when we use two LRAs for flow generation, we can use the following synthesis equation:

$$a_1(t) = a_{max}\left(\frac{t}{T}\right)^{\gamma} \text{ and } a_2(t) = a_{max}\left(1-\frac{t}{T}\right)^{\gamma} \qquad (1)$$

where $a_1(t)$ and $a_2(t)$ are the accelerations of two LRAs, a_{max} is maximum acceleration, T is signal duration, t is time, and γ is “tactile gamma” that controls the perceived quality of vibrotactile flow. Figure 3 illustrates the effect of γ on the acceleration profiles. Eq. (1) is an extended form from what we used in our preliminary study [4].

We conducted comprehensive user experiments for the various values of T and γ. Participants perceived vibrotactile flows rendered using the parameters by holding a mobile device in the hand. Example trajectories of perceived vibration position and intensity are given in Figure 4. The left panel clearly shows that the perceived vibration position moved from one end to the other end of the mobile device. The right panel shows the variations of vibration perceived intensity over time.

In [4], we showed that the perceived travel distance of vibrotactile flow is dependent on γ and T. Our more recent evaluation included a larger number of experimental conditions and response variables [5]. In particular, the results indicated that the confidence of participants for vibrotactile flow, i.e., the perceptual similarity of superimposed vibration to continuous flow, was a function of γ, as shown in Figure 5. The confidence rating was the highest when $\gamma = 1.0$. Overall, our findings suggest that vibrotactile flows can be reliably rendered using amplitude inhibition, and their perceptual qualities can be controlled by varying several parameters, especially tactile gamma.

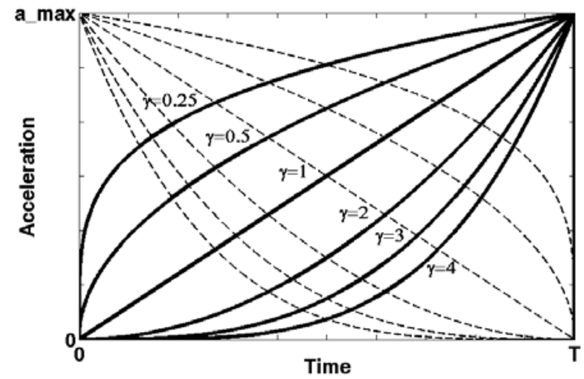

Figure 3: Acceleration profiles of two vibration actuators using amplitude inhibition.

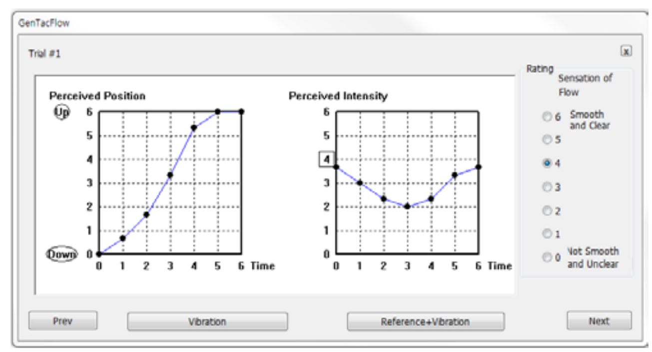

Figure 4: Example of perceived position and intensity reported in a user experiment that employed an open response paradigm.

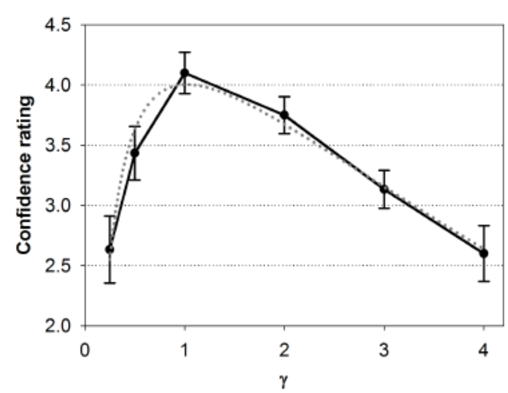

Figure 5: Subjective confidence ratings of vibrotactile flow determined for the various values of γ. T = 2~4 s (was insignificant factor for the confidence) for two LRAs separated by 8 cm.

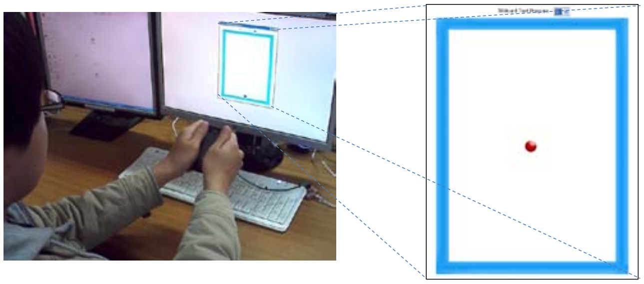

Figure 6: Ball rolling game.

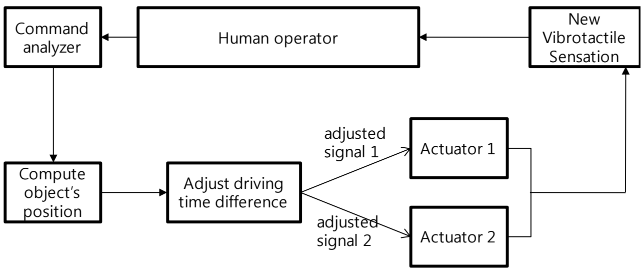

Figure 7: Block diagram for the ball rolling game.

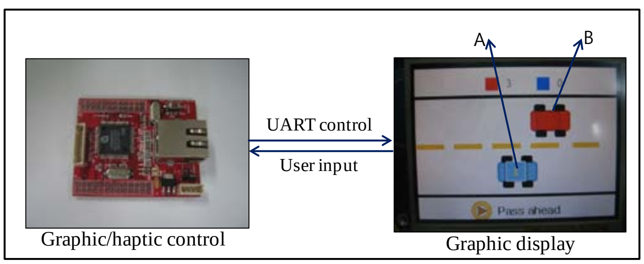

Figure 8: Driving game.

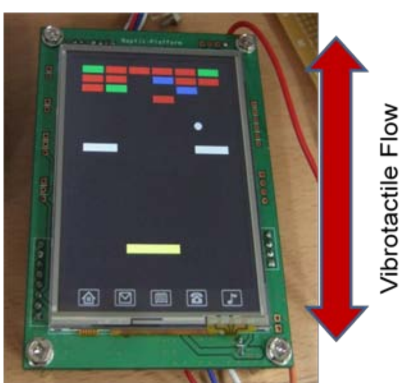

Figure 9: Arkanoid with vibrotactile flow.

4. APPLICATIONS

In order to demonstrate the usefulness of vibrotactile flow, we implemented several applications. The first example is a ball rolling game shown in Figure 6. During the game, a player can experience visual and haptic information by tilting a mobile device to move the ball. For haptic information, collision effects are provided, in addition to the dynamic behavior of the ball rendered using vibrotactile flow. Figure 7 shows a block diagram for creating the vibrotactile flow with two actuators. The user's input is interpreted by a command analyzer and then the position of the virtual ball is computed. According to the ball's position, we adjust the driving time difference between the two actuators. After that, adjusted control signals are fed to the actuators. Two vibration signals generated from these two actuators are synthesized at the ball position. Whenever the ball position is changed, a new vibrotactile flow is generated.

The second example is a car driving game shown in Figure 8, where a car (B) passes by another car (A), both running on the road. Assume that car A is located in the center of the graphic display. If car B is in the left side of car A, we overlap vibration signals at the position of car B by controlling the activation delay times of two vibration motors. If car B is drifted to the right and comes to the middle of the graphic display, both vibration motors are operated simultaneously, creating a strong vibration signal at the center of the device. When car B moves to the right further, vibration signals are superimposed at the location of car B again. This rendering algorithm delivers the position of the passing car to a user.

The last example is the classic Arkanoid, but augmented with vibrotactile flow feedback. The mobile device shown in Figure 9 has two LRAs at the two long ends. When a ball moves between blocks and bars, suitable vibrotactile flows are rendered based on the synthesis equation in Eq. (1), in addition to short vibrations for collisions. This demo was presented in the Haptics Symposium 2010.

5. FUTURE RESEARCH ISSUES

Vibrotactile flow is an effective and efficient method for delivering directional information using a mobile device grasped in the hand. To date, our research has concentrated on the feasibility of vibrotactile flow creation using two common commercial actuators (ERMs or LRAs), the investigation of their perceptual characteristics, and the demonstration of their applicability (mostly using games).

To fully realize the great potentials of vibrotactile flow, research efforts need to be expanded to 2D cases where three or four actuators (e.g., those placed at the four corners of a rectangular mobile device) would be necessary. Vibrotactile sensations that can move along any direction in the 2D plane have high promise for the intuitive delivery of 2D directional information. We are currently investigating the physical and perceptual characteristics of 2D vibrotactile flow.

Thus far, the applications that we developed were mostly related to gaming, as it is an appropriate domain to demonstrate the intuitive and fun experience of vibrotactile flow. We also foresee its potentials for more serious applications, e.g., as a navigation aid in a mobile device for the visually impaired. This would require the mobile device to be equipped with sensors for location estimation, such as GPS and digital compass, and a rendering algorithm of vibrotactile flow to be integrated with the sensor information. Development of adequate rendering algorithms and selection of optimal parameters based on user performance would of critical importance as well.

6. CONCLUSIONS

Vibrotactile flow is a sort of tactile apparent motions that we can perceive from a handheld rigid object that has two or more vibration actuators. It is a simple yet robust tactile effect that can provide directional information with minimal additional hardware. In this short position paper, we briefly introduced the rendering algorithms, perceptual performance, and applications of vibrotactile flow. The coverage was not very comprehensive because the research is at an early phase, but we do hope that this paper could prompt more research and development efforts from the haptics and human-computer interaction communities.

As the last note, LG Electronics released in 2009 a new “chocolate phone” that included two vibration actuators (one ERM and one LRA) for more diverse vibrotactile effects [Personal communication with LG Electronics]. Given the rapidly evolving and extremely competitive environments of mobile devices, it is likely that actual mobile products with the vibrotactile flow capability would be available in the near future.

7. ACKNOWLEDGMENTS

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