

Investigating the Influence of Temporal Intensity Changes on Apparent Movement Phenomenon

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Abstract— This paper aims at investigating the influence of the temporal intensity changes of two low-resolution vibrotactile actuators on the apparent movement phenomenon. In our work, we exploit two human sensory illusions called funneling illusion and apparent movement phenomenon. By temporarily varying the intensities of two adjacent vibrating actuators located on the dorsal of the human forearm, we obtained the illusion of a continuous movement of one tactile stimulus. In this work, we investigated the quality of the apparent movement according to the intensity change of the vibrating motors in a linear and logarithmic pattern. Psychophysical experiments revealed an interesting relationship between the distance and orientation of the two vibrating actuators with the preferred intensity variation, which are presented in this paper.

Keywords- *Funnelling illusion; tactile device control; continuous sensation; aparent movement phenomenon.*

I. INTRODUCTION

With the growing trend of multimodal human-computer interfaces, the human body surface has been considered as an additional means of presenting information using tactile and kinesthetic devices [13]. From an earlier stage, researchers have attempted to replace vision systems for the blind with tactile systems to provide verbal information [12]. Recently, tactile cues are used for presenting extra information such as a directional cue in a car [8], interaction for touch screen mobile devices [4], tactile music [9], a touch sensation in a remote interpersonal communication [7], etc. Tactile devices are usually composed of an array of actuators that consist of a broad range of tactile actuators, such as vibrating motors, electrodes, piezo ceramics, pneumatic tubes, voice coils, etc [3]. In general, tactile arrays are of low resolution due to the size of the actuators and the coarse sensitivity of two-point limen on the skin. Therefore, in order to provide more perceptible and subtle information, such as continuous sensation with low resolution devices, there have been endeavors to display more detailed shape exploiting human sensory illusion. In this context, the apparent movement sensation is useful as it allows us to overcome the limitation of low resolution tactile devices. In this work, we investigate the influence of temporal intensity changes in correspondence to the vibrotactile actuators' distance and orientation to enhance

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the quality of tactile displays.

The remainder of this paper is organized as follows: Section 2 gives an overview of previous work on human tactile sensory illusions; Section 3 describes the background of the funneling illusion and apparent movement sensation; Section 4 discusses our proposed method to create an apparent movement sensation; Section 5 gives an overview of the tactile device; Section 6 describes our psychological experiments in detail; Section 7 presents and discusses our results; and Section 8 concludes this paper.

II. PREVIOUS WORK

Tan et al. used one form of sensory illusion called sensory saltation, also known as cutaneous rabbit, by conveying directional information on the back of a human body with a rectangular 3 by 3 tactor array for wearable tactile displays [11]. Sensory saltation was demonstrated when three tactors were attached separately on the back of a human body. Three brief pulses were delivered to the first tactor, followed by delivering three more brief pulses to the second tactor, and finally delivering three more brief pulses at the third tactor. The user had the impression that the pulses seemed to be crawling up the spine. None the less, the user still perceived discrete taps instead of a continuous sensation. Mizukami and Sawada [10] utilized the apparent movement illusion to draw characters on the palm with a 3 by 3 vibrotactile device. With apparent movement, when two locations on the human skin are excited by two vibratory stimuli with transient time delay, the user perceives an illusory sensation which continuously moves from the first stimulus location to the other. However, the time delay should be at around 500ms in order to perceive a novel rubbed sensation on the palm [10]. Creating an apparent movement, we exploit the funneling illusion, as described in [2], where two fixed vibrotactile actuators produce a continuous sensation that moves along the skin. Alles [1] reported that the movement sensation is perceived to be equally intense along the movement path when applying a logarithmic intensity variation with two tactile stimuli. In this work, we further investigate the logarithmic intensity variation by adding additional dimensions, specifically the distance and orientation of the two vibrotactile actuators on the forearm.

III. INTERACTION AMONG MULTIPLE STIMULI

Funneling is a human sensory illusion describing a midway phantom sensation between multiple stimuli when they are

presented simultaneously and separately at adjacent locations on the human skin [1]. Figure 1(a) illustrates the funneling illusion. The circles at the first layer show the location and intensity of two tactile stimuli. At the lower layer, the larger circle corresponds to the midway sensation based on the intensity ratio of the applied haptic stimuli. Two tactile stimuli are funneled into one midway sensation, and the perceived intensity relates to the intensities applied. The location of the funneled sensation can be modified in two ways: temporal inhibition and amplitude inhibition [1].

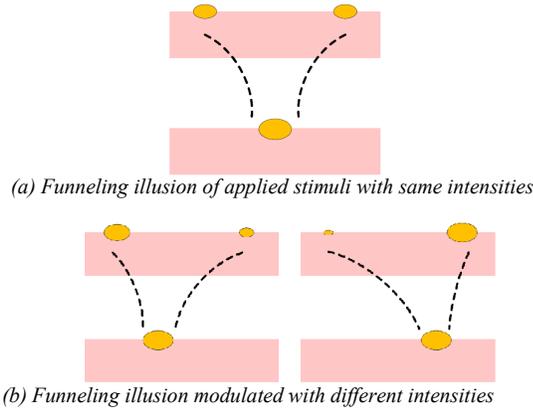


Figure 1. Illustration of the funneling illusion. The size of the circle represents the intensity of the vibrotactile stimulus.

Temporal inhibition occurs as the activity of the vibrotactile actuators are activated at different time intervals in a particular pattern with same intensity. The perceived location moves towards the earlier stimulus. However, when the time interval goes over a certain threshold, the funneling illusion disappears, and the two stimuli are felt separately. For amplitude inhibition, it applies when the activity of the vibrotactile actuators are activated at the same time, as shown in Figure 1(b). The presented stimuli are funneled and the perceived stimulus locates towards the actuator with higher intensity. In this paper, we exploit the amplitude inhibition phenomenon to create the apparent movement illusion, as it can produce a stronger funneling illusion compared to the temporal inhibition as proven in [1]. The apparent movement illusion is created by exploiting the funneling illusion discussed above. By systematically controlling the intensity of adjacent vibrotactile actuators, we are able to display a continuous moving sensation along the range of stimulation. The apparent movement phenomenon shows effective results as described in [10].

IV. DISPLAYING APPARENT MOVEMENT SENSATIONS

We are exploiting the psychophysical effect by amplitude inhibition related to the funneling illusion. An illustration of our approach is described in Figure 2. We propose to change the intensities of adjacent tactile stimuli in opposite directions. In other words, one tactile stimulus intensity changes from small to large intensity while the other changes from large to small. Therefore, the resultant sensation moves from the left stimulus location to the right. However, these discrete perceived stimuli can be felt as one continuously moving stimulus in the context of an apparent movement. Based on the

psychophysical funneling illusion and the apparent movement phenomenon, we are able to display a continuously moving vibrotactile sensation. However, from literature [1] it is known that the quality of the presented apparent movement sensation depends on the intensity variation when cross fading from one actuator to another. Additionally, in the literature [1], it was established for different distances, either a linear or a logarithmic intensity variation was preferable to human users. In our presented work, we investigate the influence on apparent movement quality with two temporal intensity change functions which are linear and logarithmic; with respect to different distances and orientations of the vibrotactile actuators.

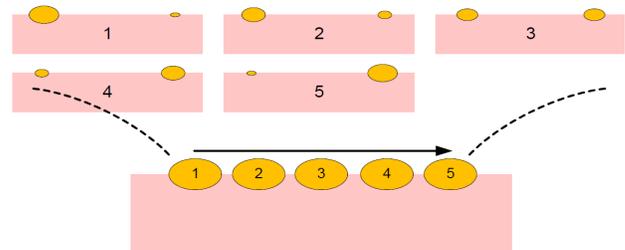
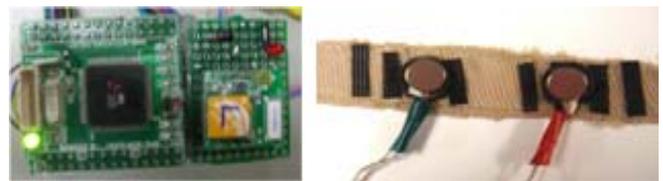


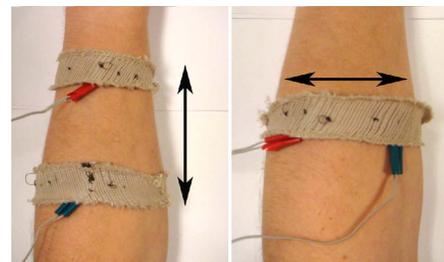
Figure 2. Illustration of the simulation of a continuous movement sensation exploiting the funneling and apparent movement illusion. The numbers denote the discrete steps which are successively applied.

V. OVERVIEW OF THE TACTILE DEVICE

Tactile cue devices often use vibration motors to act as vibrotactile actuators. In our work, we chose a pancake-type vibrating DC motor, usually used in cell phones. The small vibrotactile actuators have useful properties for our tactile device, as it is lightweight, inexpensive, have a small power consumption and easy to implement. Its operating voltage range is 3.6 volt and its operating frequency range is 220Hz, which is adequate to produce vibrations on the skin for tactile feedback as described in [5]. In order to control the intensity of the vibrotactile actuators, a microcontroller, ATmega128 with 5V operating voltage as shown in Figure 3(a) is used. The microcontroller is connected to the PC through a RS232 serial port to transfer the haptic control data. Each vibrotactile actuator provides 15 levels of applied intensities by using PWM signals, as conducted in previous work [6].



(a) Microcontroller(ATmega128) (b) Vibrotactile actuators on the armband strap



(c) Longitudinal Orientation (d) Transverse Orientation

Figure 3. Illustration of the tactile device and the experimental setup

To determine the relationship between the applied intensity level and its perceived intensity within the human haptic sensory system, a psychophysical experiment was established in [6]. The results are shown in Figure 4, where the average subjectively perceived intensities with standard errors as a function of the applied intensity level. The result demonstrates that the perceived intensities stay in almost linear ratio up to level 12. In this work, we limited the vibration dynamics to the range of control values from zero to twelve to assure a linear tactile excitement when driving the actuators. The vibrotactile actuators are attached and detached on armband straps through Velcro that are separated by specific distances. The location of the actuators can be changed freely for experiments as shown in Figure 3(b). This allows for displaying transverse and longitudinal directions (see Figure 3(c) and Figure 3(d)). The armband straps are made from nylon which makes it a flexible, elastic, tight material such that the two vibrotactile actuators attached on the Velcro of the straps will be pressed tightly on the skin of the human subjects. This ensures a strong sensation from each vibrotactile actuator as the armband straps are wrapped around the subjects' dorsal forearm.

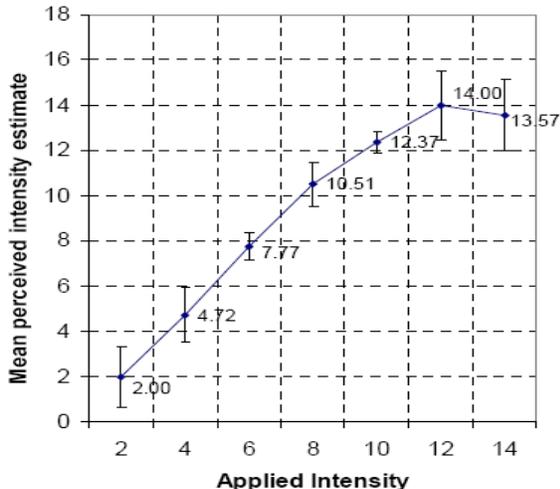


Figure 4. Average subjectively perceived intensity with standard deviation according to applied intensity levels of the vibrotactile actuators.

VI. EXPERIMENTAL SETUP

From the university community 14 subjects participated, consisting of 6 males and 8 females. For the experimental setup, two sessions took place for the subjects. First, a training session was prepared for the subjects to become familiar with the influence of linear and logarithmic intensity variations along the transverse and longitudinal directions on the forearm. For a linear variation, the intensity of one vibrating motor B was increased linearly from level 0 to 12 to stay within the preferred dynamic range of the perceived intensity as discussed in Section 5. The other motor A, intensity decreases linearly from 12 to 0 as proposed in [6]. The same approach was done for the logarithmic variation, whereas the intensities of the two vibrating motors were changed logarithmically within the same dynamic range. The logarithmic shapes were selected based on subjects' preference which they described as the best apparent movement during a prior pilot study. The applied intensity cross fading functions are shown in Figure 5.

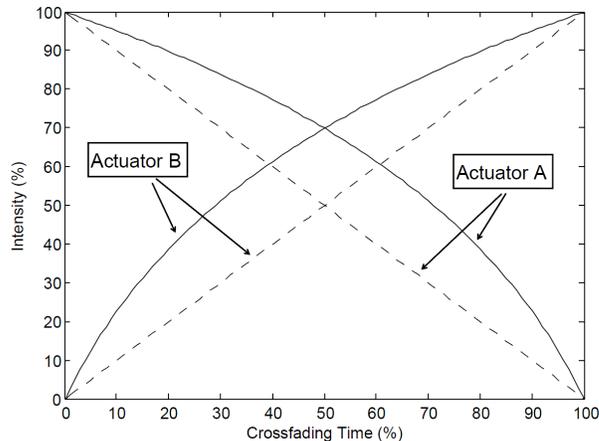


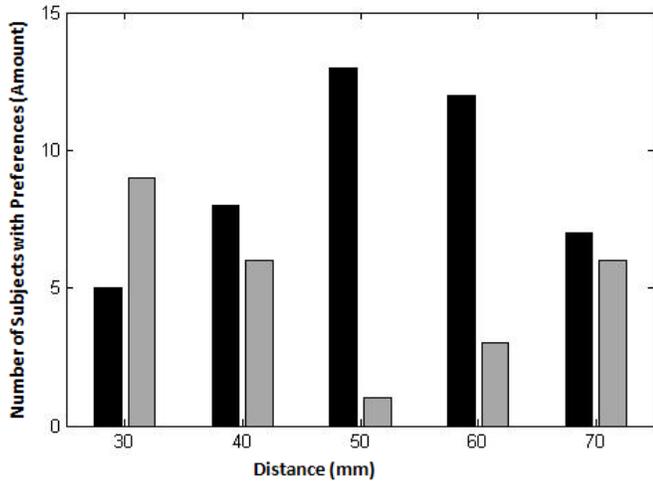
Figure 5. Illustration of the applied intensity variation function. The dashed line represents the linear change in intensity between two adjacent actuators A & B, meanwhile the solid line shows the applied logarithmic intensity variations.

During the training session, the subjects were asked if they felt an apparent movement of one stimulus without perceiving two separated stimuli. Once they distinguished between the linear and logarithmic variation, the experimental test began. During the evaluation session, the subjects wore headphones playing white noise to ensure they were unable to hear auditory cues from the vibrating motors. The apparent movement was examined as we wrapped the armband straps around the subject's dorsal forearm along the transverse and longitudinal direction. For the transverse direction, two actuators are placed on one armband strap. For the longitudinal direction, each actuator is placed on a separate armband strap. This setup is illustrated in Figure 3(c) and Figure 3(d). For each orientation, 5 distances were varied in a random order. For both orientations, the distances of the actuators were changed from 30mm, 40mm, 50mm, 60mm and 70 mm, as an optimal apparent movement sensation within this range is to be expected as proven in [6]. For each configuration the apparent movement was applied to the subjects, simulating a continuous movement with a fixed velocity at 30 mm/s, which was pre-tested to produce a reasonable speed for the apparent movement evaluation. Two test items referring to a linear and logarithmic intensity variation were presented in a blindly manner to the subjects. They were asked to select the test item, which provides the strongest and uniform apparent movement sensation.

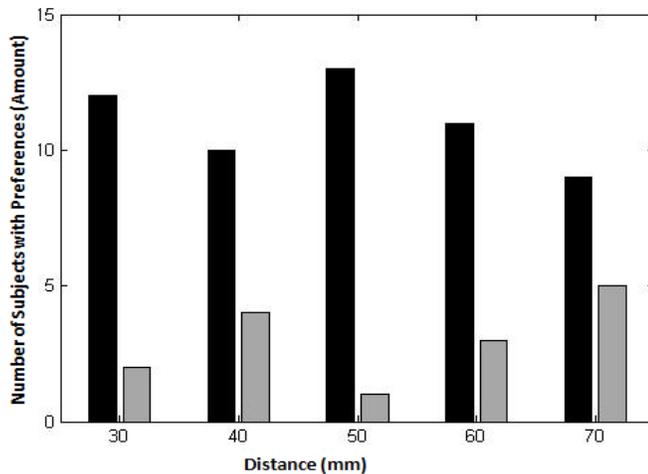
VII. RESULTS AND DISCUSSION

Based on the subjective answers of our 14 test subjects, Figure 6 shows the number of subjects with preferences of the two offered intensity variations for each distance along the transverse and longitudinal orientation. The black bars represent preferable linear intensity change, while the grey bars display the amount of preferences for the logarithmic intensity change. Surprisingly, the presented figures differ quite a lot according to the actuators' orientation. Figure 6(a) shows our results for the longitudinal orientation. For the distance of 50 mm, the linear intensity change was clearly favoured.

According to [6], this distance range is also preferable to display a continuous movement sensation. As we increase or decrease the distance from 50 mm, the amount of linear preferences decreases. Accordingly, at 50 mm, the logarithmic cross fading function was least preferred and as we increase or decrease the distance it became more preferable. By looking at the ratio of the linear and logarithmic preferences for each distance, we see an interesting Gaussian like behavior. In Figure 6(b), the results for the transverse orientation are illustrated. In this case, the linear intensity variation is strongly favoured for all distances. Unlike the results shown for the longitudinal orientation, no significant influence of the actuators distances on the subjects' choices can be found in the results. One reason, is the result of a different propagation of vibration on the human skin along the longitudinal compared to the transverse direction. Since the transverse direction utilized only a single armband strap, subjects reported a clearer and uniform continuous motion of the apparent movement transmitting from one vibratory stimulus to the other.



(a) Results for the longitudinal direction



(b) Results for the transverse direction

Figure 6. Results of our conducted psychophysical experiment based on the 14 subjects. The number of subjects with preferences for a linear intensity variation (black) and a logarithmic intensity variation (grey) according to the distances of the applied vibrotactile actuators are shown.

VIII. CONCLUSION

In this paper, we investigated critical parameters of the psychophysical apparent movement sensation. The influence on the temporal variation of intensity changes in a logarithmic and linear pattern between two vibrotactile actuators are evaluated, according to the distances and orientations of the applied actuators. This allows us to design tactile displays which present uniform moving vibrotactile stimuli with high resolution and maximized continuous apparent moving sensation. Our results show an interesting behaviour, as we obtain a favored linear intensity variation for the longitudinal orientation at a distance of 50-60mm. However, for smaller or larger distances, the logarithmic intensity variation becomes preferable. Surprisingly, for the transverse orientation, the linear intensity variation was preferred for all distances. To investigate the background of our results, further psychophysical experiments are to be conducted and will be part of our future work. Furthermore, additional research will be conducted on finding an optimum logarithmic function to provide the best possible apparent movement presentation.

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