# Studies of Vection Field II: a method for generating smooth motion pattern

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## ABSTRACT
Along public pathways, visual signs and audio cues are used by pedestrians to guide them into forming smoother pedestrian flows. However, often ignored or neglected, these signals require greater pedestrian attentiveness and appropriate conscious effort. To solve this problem, we have proposed the concept of "vection field". This is a field of optical flow that cues movement according to a pedestrian's motion. Visual stimulus within this optical flow leads pedestrians innately in specific directions without requiring direct interventions. We have implemented such a field by covering the ground with a lenticular lens screen; in this setup, neither power supply nor position tracking of pedestrians is necessary. An experimental result from our previous study shows that a vection field can direct pedestrians to one side. However, the quality of the optical flow such as image clarity and smoothness of motion was unsatisfactory in that it could cause a reduction in leading inducement. In this paper, we describe in detail a new display method involving a lenticular lens screen that yields an improvement in the quality of the vection field and ultimately pedestrian optical flow. Experiments showed improvements over previous attempts.

## Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Theory and methods, User-centered design.*

## General Terms
Design, Human Factors, Theory

## Keywords
Lenticular lens, Traffic control, Vection

## 1. INTRODUCTION
Pedestrians often encounter difficulties due to congestions and confrontations in their walks along public path ways. Visual signs and audio cues are commonly used to reduce such difficulties for a smoother pedestrian flow; for example, directional signs painted on the ground to remind pedestrians to "keep right". However, those messages are often ignored or neglected, requiring pedestrian attentiveness and conscious effort for effectiveness. A more intuitive means is necessary to convey such messages. Moreover, those messages, as valuable as these are in forming smoother flow, must vary according to a pedestrian's direction of travel. For example, "keep right" is one typical message that has to be seen from either direction along some street or corridor. "Right" in this message means, of course, the "pedestrian's right". From the perspective of some fixed frame, "right" is different from person to person depending on their direction of walking. Thus, to establish smoother pedestrian flow, those messages should be specific and displayable to each pedestrian according to their situation.

Much research has been undertaken to display such navigational aids in an intuitive way. Wearable devices with haptic stimuli [1][2][3] or with vestibular stimuli [4] are often proposed. However, these wearable devices are for personal navigation and are not suitable to establish "smooth pedestrian flow" because numerous devices are required. Therefore, it is preferred to install intuitive cues in an environment. G. Boehm has proposed using environmental visual cues that induce illusory barriers to modify pedestrian flow dynamics [5]. By his method, pedestrian flow shifted as if they avoid the barriers. However, it seems that pedestrians were able to see the barrier only from a particular position and his method is not effectual in intermingling, contrary flows. Thus, it is desirable to adapt the cues to each pedestrian.

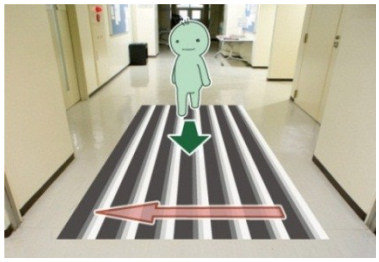

**Figure 1: "Vection field" is a moving visual cue triggered by relative motion of viewer.**

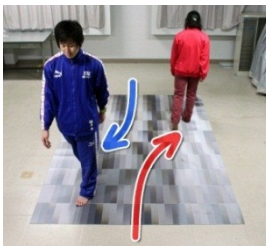

**Figure 2: Lenticular lens configuration**

In our study, we have focused on the dominance of vision on body balance [6] [7], and proposed the notion of "vection field", which



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is a novel means to induce preferred motion (Figure 1). The large visual cue presented on a floor, motions pedestrians to preferred side depending on his/her direction of motion [8]. For projecting the visual cue for each pedestrian, we produced this visual cue using lenticular lenses [9]. A lenticular lens is a sheeted array of cylindrical lenses under which different images appear depending on the viewing angle; when viewed in motion the system achieves a type of animation. With the use of these lenses, no electrical supply is required to display or animate the image. Moreover, the configuration is exactly the same for the two viewers in opposing motion. As seen in Figure 2, the woman walking away from the camera over the vection field, sees a rightward-moving pattern; the man moving towards the camera observes a leftward-moving pattern (for him, this would be rightward-moving).

For the original prototype, we prepared lenticular flooring containing a rightward-moving black-white striped pattern, which we used to induce a lateral-leading effect. We called this "Flip-book Motion Pattern" (FMP) because each image appears like a flip-book. However, that visual cue had two fundamental problems: First, the borders between the black and white stripes were fuzzy; and second, the motion of the stripes was discontinuous. In this paper, we will discuss the causes of these problems and propose a new method to solve them. Furthermore, we have made a simulation of a newly-developed method. We have evaluated its lateral-leading effect compared with FMP. In this experiment, we have prepared two simulated vection fields using image projection. The result shows that our newly-proposed method induces more lateral-leading than the FMP-based stimulus.

# 2. IMPLEMENTATION

## 2.1 The cause and solution of two difficulties

FMP, the original prototype, included six images that produced the frames for the animation. The first difficulty arose as we assumed that the animation could be produced with very few frames. If an observer views FMP from an oblique viewing angle, the border between stripes becomes fuzzy. The second difficulty is also related to too few frames. Because the gap between frames was large, an observer sees a discontinuity in the motion of the strip when passing from one frame to the next frame. Under these considerations, it would be ideal if the lenticular flooring included an infinite number of frames. The observer would then be able to see clear images at various viewing angles because from frame to frame the number of possible viewing angles increases. Moreover, stripe motion will be smoother because gaps between frames would be narrower. In producing a second prototype, the flooring consists of a continuous frame that essentially mimics an infinite number of frames. We called this setup a "continuous motion pattern" (CMP). Figure 3 shows a schematic of the observed images along the viewing angle and the frames under the lenticular flooring for both FMP and CMP. One can see the discontinuity in successive frames for the FMP. In contrast, tilted black lines a produced from the lenticular lens system for the CMP.

## 2.2 Parameter

The image under the lenticular lens is magnified uniaxially and merges with the next magnified image. Frames magnified by the lenticular lenses then appear. For CMP, a partial intersection of lens occurs and the tilted black lines are magnified to combine with the next magnified images. Therefore, a well-defined black and white stripes pattern appears. In this section, we will describe the displaying of the CMP.

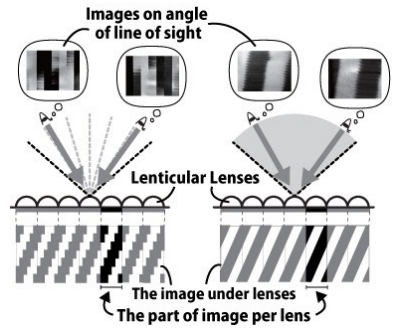


**Figure 3: Observed images along viewing angle and images under the lenticular lens system [Left] FMP: First Prototype, [Right] CMP: Second Prototype**

### *2.2.1 The display model of CMP*

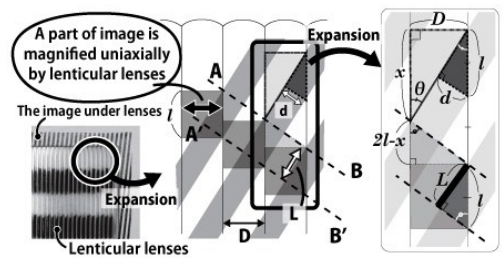


**Figure 4: Model of observed lines**

As shown Figure 4, $D$ is the width of each lens, $d$ is the width of a tilted line under the lenses and $\theta$ is the angle of tilted lines relative to the plane of the lenses. Therefore, $l$ which is the length of a magnified line per lens is obtained from the following expression:

$$l = d/sin\theta \tag{1}$$

Moreover, from geometric considerations, we introduce the constant number $c$ as the ratio $D/d$; that is,

$$D = cd \tag{2}$$

$$x = cl \cdot cos\theta = cd/tan\theta \tag{3}$$

Therefore, $x$ in Figure 4 indicates the range over which an observer focusing on one lens will see a black strip in the frames beneath the lens. The magnified images combine contiguous images and the observer sees stripes contained within the area between lines AB-A'B'. The width of the observed stripes $L$ is given by:

$$\frac{L}{D} = \frac{l}{\sqrt{(2l-x)^2 + D^2}} \tag{4}$$

$$\mathrm{L} = \frac{Dl}{\sqrt{(2l-x)^2 + D^2}} \tag{5}$$

$$= \frac{Dd}{sin\theta\sqrt{\left(\frac{d}{\sin\theta}(2 - c\cdot\cos\theta)\right)^2 + D^2}} \tag{6}$$

If $D$ and $d$ are fixed, then $L$ depends only on $\theta$; as $\theta$ narrows, $L$ becomes wider because $L$ reaches $\infty$ when $\theta$ reaches 0.

### *2.2.2 The motion speed of the stripes*

As the viewer moves forward, he sees the stripes move laterally, to the right in our prototypes. We can calculate the translational speed of the stripes.

If $\phi$ in Figure 5 denotes the viewing angle and at this point in the line of sight from the first frame to the end, the viewer sees the

stripes move $cd/tan\theta$. If a viewer of height $H$ walks forward while viewing a fixed point and his angle through line of sight opens to $\phi$, $z$ which is the distance from first point to the end is $2Htan(\phi/2)$. Hence, when the viewer walks 1[m], he observes the stripes pattern shift by distance

$$w = \frac{cd}{z \cdot \tan\theta} = \frac{cd}{2H \cdot \tan(\phi/2) \cdot tan\theta}. \quad (7)$$

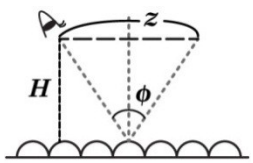


**Figure 5: Dynamics of the viewed stripes**

## 2.3 Implementation for CMP

We produced a working CMP, prototype using lenticular lenses of width $D = 1.27$ [mm]. We set $c = 2$ so that the width of a tilted line under the lenses is $d = D/2 = 0.635$ [mm]. If the image under the lenses is further tilted, the width of the viewed stripes changes; i.e. the greater the tilt, the thicker the width. The main point though is that the border of the viewed stripes is clearer and the motion of the stripes is smoother than for FMP. The Figure 6 shows the sample picture of both FMP and CMP. In this design, pedestrians walk longitudinal direction then stripes on both FMP and CMP move laterally.

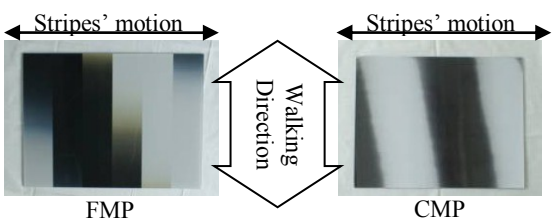


**Figure 6: Viewing comparison of FMP and CMP**

# 3. EVALUATION

## 3.1 Comparison of Luminance Values

In this section, we evaluate space and orientation resolutions of both FMP and CMP so as to measure luminance values of both images to see whether CMP does improve the two main difficulties.

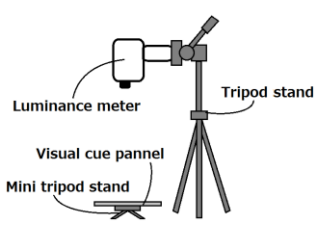


**Figure 7: Schematic of experimental setup (side view)**

When pedestrians stand on the panels, they see stripes with laterally low resolutions (FMP) or with high resolutions (CMP). We define these lateral resolutions as "space resolutions" and evaluate it in 3.1.1. If pedestrians walk on the panels, they see those stripes move laterally according to the change of viewing angle. We define this as "orientation resolutions" and evaluate it in 3.1.2. Figure 7 shows a schematic of this experimental setup. A luminance meter was set on a tripod stand and directed towards the floor. Directly under the luminance meter, we placed a small section of the visual stimulus panel on a mini sized tripod stand. The size of the panels was 0.30[m] x 0.23[m]. By horizontally sliding the panel and stand from end to end, we were able to measure the space resolutions of the panel. These measurements were taken at 1 cm intervals. Orientation resolution measurements are realized by tilting the flat panels from the horizontal positions. The panels were tilted at 2[deg] increments from -20[deg] to 20[deg], 0[deg] being the horizontal position.

### *3.1.1 The space Resolutions*

The results are shown in Figure 8. The vertical axis corresponds to luminance values. Thus, if a luminance value is higher, the point is brighter and the viewer sees a white point. The horizontal axis indicates the measured point [cm]. The blue circle marks represent the FMP data, the red x marks correspond to CMP data. For the FMP panel a zone of medium luminance is clear to see and gives rise to the fuzzy appearance of the black and white stripes. In contrast, the luminance for CMP changes more smoothly.

### *3.1.2 The orientation Resolutions*

The results of the orientation resolutions are shown in Figure 9. The horizontal axis indicates the tilt angle of the panel [deg]. As shown in this graph, there is little difference between FMP and CMP other than a greater loss in luminance at certain measured points.

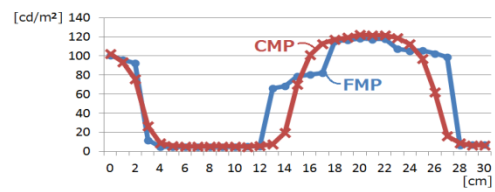


**Figure 8: Panel luminance according to lateral displacement**

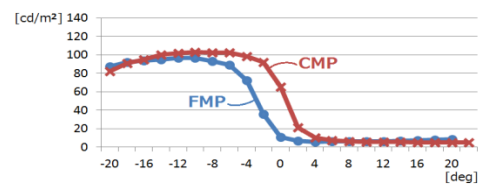


**Figure 9: Panel luminance according to orientation**

### *3.1.3 Discussion*

As described in section 3.1.1, luminance values from the CMP panel exhibit a smoother transition than from a FMP panel. Therefore, this result suggests that the border between the black and white stripes would be more clearly visible. In contrast, the difference in orientation resolution between FMP and CMP panels as described in section 3.1.2 is not so great. However, in our previous research, many people who experience the system commented that the stripes' motion of FMP seems discontinuous. The reason why FMP appears discontinuous is because the viewing zone for when the stripes turn from black to white has a time lag and hence becomes shifted horizontally.

## 3.2 Simulation

We have physically demonstrated that the visual motion for CMP and FMP are different. CMP resolves the difficulties arising from FMP; CMP exhibits better visibility than FMP. However, does that better visibility translate into inducing preferred pedestrian motion? To examine differences in the lateral-leading effect, we simulated the animated imagery for both FMP and ideal CMP (i.e. infinite number of frames) which we then used in single-pedestrian trial simulations projected onto the floor.

### 3.2.1 Experimental Setup and Method

Using a short focus projector and a monitoring system to record the motion of walking subjects, we conducted a simulation of the visual stimuli. Figure 10 shows a schematic of this experimental setup and the visual stimuli which gave a floor area of 3.5[m] × 2.0[m] when illuminated by the projector. Both visual stimuli when viewed under forward motion show animation moving to the right side. A web camera tracked the depth of the subject using an AR marker, made of a retro-reflective sheet located on the subject's back that reflected the LED light on the web camera. The subject's depth was tracked for real-time rendering of the stimuli. This program was produced within processing environments, ARToolKit tracking library [10] and QPToolKit, which is a framework for position measurement based on ARToolKit [11].

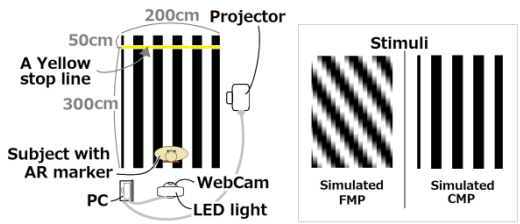


**Figure 10: Schematic of simulation experimental setup (top view) and two visual stimuli**

Each subject was instructed to stand at one end of the stimuli and centered with the aid of a projected centerline; the centerline was then removed. While gazing at a point on the floor one step ahead the subject was asked to start walking and stop upon reaching a yellow stop line at the other end. The yellow stop line was always appeared 300[cm] ahead of the start point. The experimenter then measured the lateral displacement of the subject. For each subject, this experiment was conducted over a total of ten trials, with five trials for each visual stimulus. The conditions were generated randomly. The average age of the six subjects was 23 years (S.D±0.75), and the average height was 164cm (S.D. ±1.86).

### 3.2.2 Results and Discussion

The results are shown in Figure 11. The vertical axis indicates lateral displacements from the centerline to the point where the subject stopped at the yellow stop line; error bars indicate standard deviations. As shown in the graph, five of the six subjects showed a greater susceptibility under the simulated CMP to be laterally displaced. However, the results show great variations between subjects; for example, the inducing effect of subject E shows large dispersion in the simulated FMP. In contrast, the dispersion in CMP of subject C is larger.

Showing a larger displacement of the simulated FMP, subject B reported it was more difficult to bring his body into balance on the simulated FMP than CMP. In this case, it was suggested that larger displacement resulted from intent to recover from this imbalance, not by the lateral-leading effect. Some of the subjects also reported losing the directional sense of motion from the simulated FMP and felt sick. The subjects were possibly overwhelmed by the fuzzy and discontinuous motion of FMP.

## 4. CONCLUSION

In this paper, we addressed difficulties arising with FMP and proposed solutions as to how to implement the "vection field". We produced CMP as an outcome and demonstrated its effectiveness by physically measuring the luminance value of this panel. Furthermore, we evaluated whether CMP, viewed as a nearly ideal stimulus, would have a greater laterally-leading effect for a walking subject than FMP, which due to its fuzzy and discontinuous motion stimulus might be a hindrance. As shown Figure 11, the ideal stimulus tended to induce greater lateral displacement, thereby demonstrating that CMP also would exhibit greater lateral-leading inducement than FMP.

For the near future, we will be considering additional experiments to optimize stimuli such as width of stripe pattern and viewing range.

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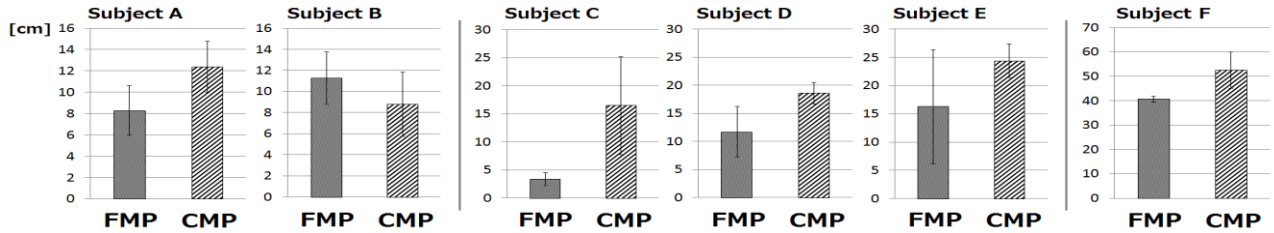


**Figure 11: Results of lateral-leading for each stimulus**