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Perception of 3D Structure from Steady Velocity Field Produced by Cyclic Display of Multi-Phase Images

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Human visual system can perceive 3D structure from optic flow or velocity field. We confirmed the 3D structure perception from the steady and continuous velocity field produced by cyclic presentation of several correlated random dot images. In addition, we investigated the velocity field perception for the factors of the number of phases (n), the temporal duration (ΔT) and the positional deviation (Δd). Then, we found that there is suitable range of ΔT and Δd for given n in which the velocity field could be perceived clearly.

1. Introduction

In the recent years, many works have been done on the questions of how the visual system extracts the three-dimensional structure of an object from two-dimensional motion. Human visual system can perceive 3D representations such as depth, surface, structure, volume and so on from the retinal image motion: which are called as 'X' from motion[1–5]. The motion perception can be created by successive disparity: which means positional deviation in time course. We can perceive continuous motion from the sequence of snapshots with suitable time intervals: which is called as an apparent motion perception[2] and has been applied for many visual displays such as movies, television, and video.

2. Steady Velocity Field Produced by Cyclic Display of Multi-Phase Images

We tried to use several sequential snapshot images with correlation each other and displayed them cyclically[6–10] as shown in **Fig. 1**; then investigate the velocity field perception for the factors relating the apparent motion perception[11].

The factors considered are the number of phases (n), positional deviation between the correlated images (Δd) and the temporal duration (ΔT).

In these correlated random dot images, the dots are distributed in the specific position and are slightly deviated between successive images, here we use the visual angel ($\Delta\theta$) to denote the positional deviation of dot by Eq. (1) as shown in **Fig. 2**.

$$\Delta\theta=(\Delta x/D)*(180/\pi) \qquad (1)$$

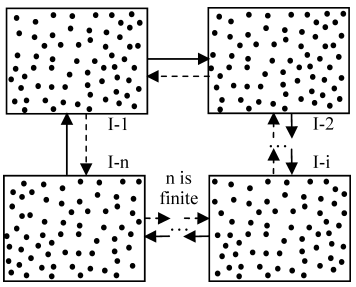

Fig. 1. Illustration showing the cyclic display of multi-phase images; the multi-phase images including a set of correlated images {I_1, I_2, ⋯Ii, ⋯I_n}, and the number of n is finite. The velocity field ($V_{f(x,v)}$={$V_{xv(Vx,Vv)}$}) is formed and the steady velocity field can be perceived.

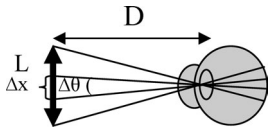

Fig. 2. Schematic diagram showing the visual angel $\Delta\theta$ for positional deviation Δx: which calculate by Eq. (1)

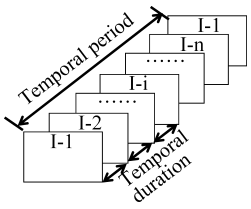

Fig. 3. Temporal duration (ΔT) and temporal period (n=T).

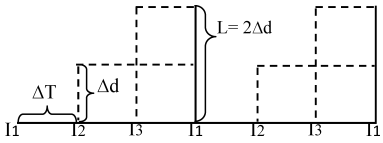

Fig. 4. Schematic figure show the relation between three factors for the case of 3 phase.

As shown in **Fig. 3**, the duration time of each image (I-1, I-2, ⋯, I-i, ⋯, I-n) is called temporal duration (ΔT); and the summation of each image's temporal duration is called as temporal period (nΔT)[9].

Then, as shown in the **Fig. 4** for the relation between the three factors (n, Δd, ΔT), we inferred the suitable condition to produce the steady velocity field: positional deviation Δd and temporal duration ΔT should be selected within the condition in which the apparent motion is perceived, that is to say, in the suitable range of temporal duration time ΔTn–ΔTm, Δd should be less than upper limit value of deviation Dc (Δd< Dc). In addition, the return distance to the first phase image (L=(n−1)Δd) and the temporal duration (ΔT) should be selected so that the apparent motion from the last image to the first image could not be perceived. Also in the suitable range of temporal duration time ΔTn∼ΔTm, return distance (L=(n−1)Δd) should be more than the value Dc so that backward apparent motion could not be perceived (L>Dc).

In order to confirm the above speculation, we conducted several experiments using only the multi-phase images with correlation.

The experimental patterns were used as two kinds which are the vertical and horizontal direction motion pattern as shown in **Fig. 5** and **Fig. 6**.

Each pattern mentioned in the above was observed in the condition that phase number displayed from 3 phase to 4 phase respectively.

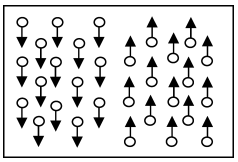

Fig. 5. Illustration of pattern 1: the motion perception from the reverse velocity field in horizontal directions.

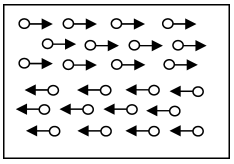

Fig. 6. Illustration of pattern 2: the motion perception from the reverse velocity field for vertical directions.

The temporal duration time of each image changed from 17 ms to 204 ms by the rate of 17 ms and the value c was changed from 0.004 to 0.058 by the rate of 0.006 accordingly the positional deviation Δd was changed from 0.13° to 1.87° in visual angel.

We used the Sony GDF-520 display (4400× 3400) and viewing distance was 71 cm. The observers viewed the entire monitor screen. After the stimulus of any trail, observer reported one of the perceptions degrees of the motion: {which were 0: unable to be perceived; 1: poorly perceived; 2: just perceived; 3: well perceived; 4: clearly perceived}.

Two examples of these results are shown in **Fig. 7** and **Fig. 8**. They are the average perception degree of the observers.

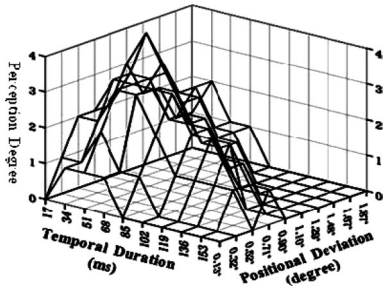

Fig. 7. Result of 4 phase case.

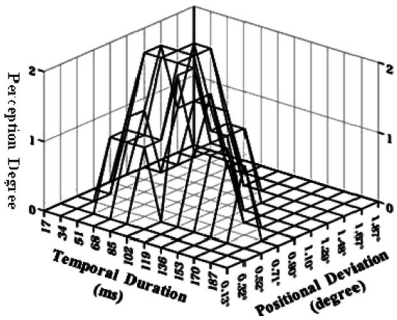

Fig. 8. Result of 3 phase case.

Table 1. Analysis of the results.

Phase(n)	Apparent Motion(Δd)	No Return Apparent Motion (L=(n-1) Δd)
3phase	Δd <1.29°	L> 1.80°
4phase	Δd <1.10°	L> 2.13°

In Figs. 7 and 8, we can see that the suitable range of the temporal duration is 34 ms~51 ms and that of positional deviation is 0.71–1.10 for the 4 phase case; while they are 68 ms–85 ms, and 0.90°–1.29° for the 3 phase case. They are summarized in **Table 1**.

From the data in Table 1, we can predict that the Δd is less than the upper limit causing the apparent motion (Dc) and the return distance (L=(n−1)Δd) is more than the upper limit value causing the apparent motion (Dc).

3. Perception of 3D Structure from Steady Velocity Field Produced by Cyclic Display of Distributed Multi-Phase Images

Based on the steady velocity field produced by the multi-phase images, we observed the

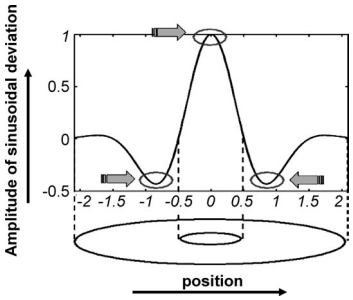

Fig. 9. Conceptual figure of structure were generated in a sinusoidal way.

Table 2. Random dots Distributed.

Whole Random dots	Divided Random dots Groups		
	G1	G2	G3
A1(phase1)	A11	A12	A13
A2(phase2)	A21	A22	A23
A3(phase3)	A31	A32	A33

Table 3. Method of distributed cyclic display.

3Frames	D1 (3phase images with blank)	D2 (3phase images without blank)
F1	A11+A23+ blank	A11+A23+ A32
F2	blank+A21+ A33	A12+A21+ A33
F3	A13+blank+ A31	A13+A22+ A31

structure from the motion perception. We move the dots on a flat plane in a sinusoidal way which amplitude of deviation is as shown in **Fig. 9**.

We used 3 phase images and divided into three groups as shown in **Table 2**; then display them clically as shown in **Table 3**. So that, each phases were distributed in each frame.

First pattern is including two correlated random dots images A11, A21, A22, A32, A33, A13 and 3 blank images: in which blank images were distributed into each frame.

Second pattern, we didn't use the blank image but only 3 phase images were distributed to frame D1, D2, D3.

We found that the random-dots producing the velocity field corresponding to amplitude

distribution in Fig. 9; and sinusoidally waved surface was perceived as stretching and squashing; in addition, when the blank images were included, perception becomes obvious. In addition, we found that there was almost no blank image perception while there was strong perception in undistributed case. Using this method we found that structure perception from the pure velocity field can be observed.

4. Conclusion

In this study, we succeed to producing steady velocity field by the multi-phase images, and found that there are the suitable ranges of the temporal duration (ΔT), the positional deviation (Δd) and phase number (n) for the perception of velocity field and structure. We inferred that (n−1)Δd should be more than Dc, at the same time, Δd should be less than Dc, for steady velocity field perception.

We succeed to generating the perception of 3D structure from steady velocity field produced by cyclic display of multi-phase images in distributed way; when the blank images are distributed to each frame, there was no obvious perception of blank image; then the structure perception from the pure velocity field can be observed smoothly.

We believed that proposed method can be applied to producing new type of velocity field and visual effect; then it can provide a new clue to revealing the 3D perceptual mechanism in motion parallax.

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