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Method for predicting motion artifacts of plasma display panels

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Abstract: A simulation method is proposed to predict the motion artifacts of plasma display panels (PDPs). The method simulates the behavior of the human vision system when perceiving moving objects. The simulation is based on the measured temporal light properties of the display for each gray level and each phosphor. Both the effect of subfield arrangement and phosphor decay are involved. A novel algorithm is proposed to improve the calculation speed. The simulation model manages to predict the appearance of the motion image perceived by a human with a still image. The results are validated by a set of perceptual evaluation experiments. This rapid and accurate prediction of motion artifacts enables objective characterization of the PDP performance in this aspect.

Key words: plasma display panels; motion artifacts; dynamic false contour; motion blur

Motion artifacts[1-2] like the dynamic false contour (DFC) and motion blur can be significant drawbacks of flat panel displays (FPDs) such as the plasma display panel (PDP) and the liquid crystal display (LCD). These motion artifacts are perceived by human eyes, but difficult to record and characterize. Based on the measured temporal light behavior of the display panel, this paper introduces a way to predict motion artifacts with a still image. Finally, the predictions are validated with perceptual evaluation experiments.

1 PDP Operation and Visual Perception Basics

A PDP[3-4] is essentially a matrix of sub-millimeter fluorescent lamps that are controlled by electronic drivers. Each pixel of a PDP is composed of three elementary UV emitting discharge cells. The UV light is converted into visible light by phosphors in three primary colors. Due to the binary state of the plasma cell (on or off), different intensities are generated on a PDP using pulse-number modulation. The complete frame duration is split into several weighted sub-fields[5] (see Fig. 1). The pulse-number denotes the sub-field weight. In Fig. 1, 32 intensities can be generated by selecting one or more sub-fields. The actual light behavior is more complicated (see Fig. 2). This figure shows the measured luminance curves of the red, green, and blue phosphors for pixel value 255. The display was active during only one frame period (60 Hz). These curves include both sub-field arrangement and phosphor decay information. For our model the luminance curves for each gray level and each phosphor are required. So in total 768 curves with temporal luminance data are needed for 8-bit input codes.

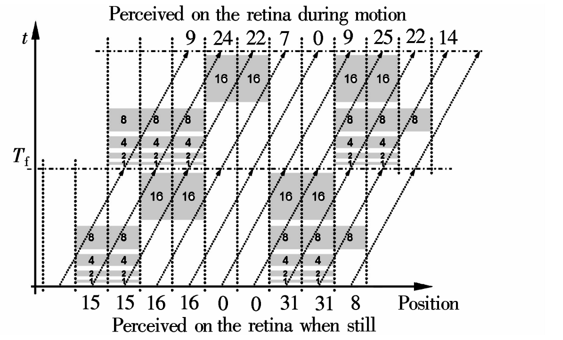

Fig. 1 The schematic diagram for subfield arrangement and motion artifacts generation

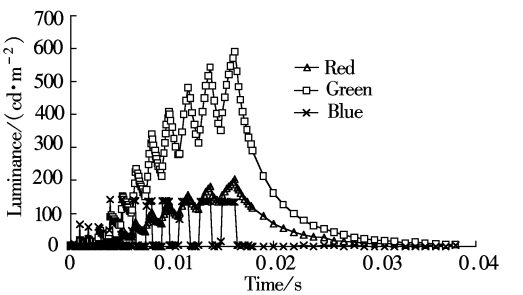

Fig. 2 Examples of luminance profiles for different phosphors when pixel value is 255

For the mechanism of motion artifacts when viewing a moving image, two valuable assumptions of the human visual system can be found in Refs. [6 − 7]: ① The viewer perfectly tracks the viewed object by smooth movements of the eyeballs; ② Light stimulus within a 1-frame period is perfectly integrated in the visual system.

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As we know, video content is displayed by discrete frame series, while the human eye perceives the moving object with smooth tracking. Depending on the subfield arrangement this may result in motion artifacts. This can be explained by Fig. 1. When no motion is present, the observers will perceive a light intensity according to the pixel values indicated at the bottom (sum of the active subfields in one frame time). When the image starts moving, for example, at a speed of 2 pixel/frame, the eye will integrate the light along the motion trajectory, indicated with the dashed arrows. The resulting pixel values are indicated at the top of Fig. 1.

2 Program for Simulation

For our model we assume that the moving original picture $P_0(m, n)$ and the still picture $P(k, l)$ (simulated for a specific motion speed) will result in the same perceived result. Where m, n, k, l describe the definition, $m = 0, 1, \ldots, M-1$; $n = 0, 1, \ldots, N-1$; $k = 0, 1, \ldots, K-1$; $l = 0, 1, \ldots, L-1$. Fig. 3 shows the schematic overview of the simulation software. The two images are indicated by $P_0(m, n)$ and $P(k, l)$, respectively. By comparing the pixel values of picture $P(k, l)$ with those of picture $P_0(m, n)$, we can derive the degree of the deviation and then the seriousness of motion artifacts.

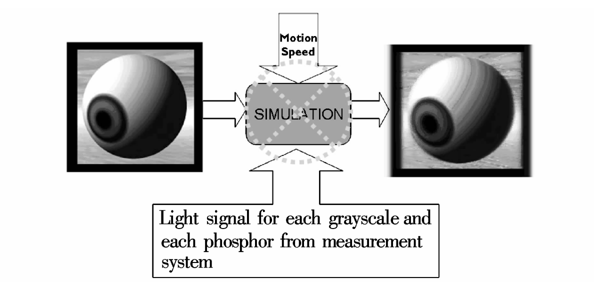

Fig. 3 Schematic overview for motion artifact simulation

To calculate the new picture $P(k, l)$, two assumptions are used:

① $M = K$, $N = L$. So the two pictures have the same size and resolution.

② $\sum_{m,n} P_0(m, n) = \sum_{k,l} P(k, l)$, meaning that the pictures generate the same amount of light.

In Fig. 4 a moving one-dimensional picture $P(j)$ is presented. It moves horizontally with a speed of 2 pixel/frame. Each integration region should be along the motion trajectory. Based on the assumptions above, the hatching parallelogram of Fig. 4 is considered as the integration region for a new pixel. The blocks (A, B, …) are pixels for the original still image. The resulting luminance of pixel j is calculated by

$$L_j' = \frac{1}{X_p T_f} \iint_{S_{xt}} L(x, t)\,\mathrm{d}x\mathrm{d}t \tag{1}$$

$L(x, t)$ is the light signal as the function of space and time. So Eq. (1) also needs the information of light distribution as the function of space, which is difficult to measure. However, if we take R, G, B sub-pixels into account, for each phosphor, the light generation almost concentrates in the middle of the pixel, like the small black dashed blocks in the hatching parallelogram of Fig. 5. We assume that the light is concentrated along the line in the center of each sub-pixel. In this case Eq. (1) can be simplified to

$$L_j' = \frac{1}{T_f} \int_{S_t} L(t)\,\mathrm{d}t \tag{2}$$

where $L(t)$ is derived the light behavior of pixels C, D, and E.

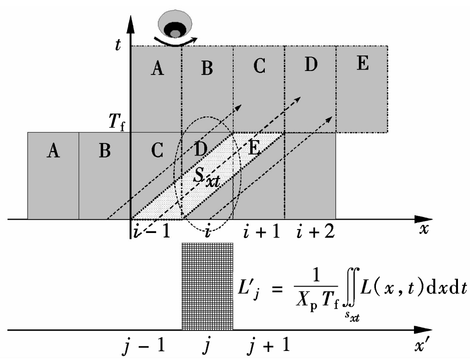

Fig. 4 Schematic of the light integration principle

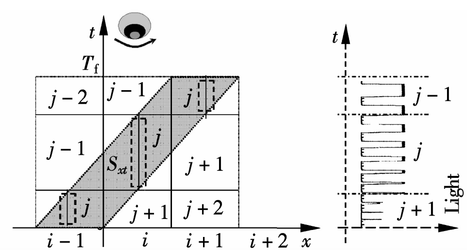

Fig. 5 Consideration of space distribution of light intensity in one pixel

In this way, to calculate all the pixels of P, the light behavior data of pixels in P_0 are repeatedly accessed, resulting in a lot of time to compute to total image. If we take phosphor decay into account, the contents of previous frames will also be affected. It is difficult to add this effect to Eq. (2).

In Fig. 5, each pixel of P_0 contributes to three pixels $j-1$, j and $j+1$ of P. If the light signal behaves as indicated at the right, it is divided into three segments, contributing to $j-1$, j and $j+1$ of P, respectively. For a certain motion speed, identical input codes will have the same curve and hence the same processing. For example, for blue = gray, we can first detect the location of all the pixels of P_0 with blue = gray, then spread the corresponding segments to the corresponding pixels of

$P(j)$. For each pixel value and each phosphor, we can get such a kind of array, and then add all of them together to get the new image P.

Due to phosphor decay, for a certain physical pixel the previous value will affect the current light behavior (see Fig. 6). The light behavior in one frame period for a particular pixel value can be separated into two parts:

① The light generated in one frame period with 0 input as the precondition.

② The light component that depends on the previous value of this pixel.

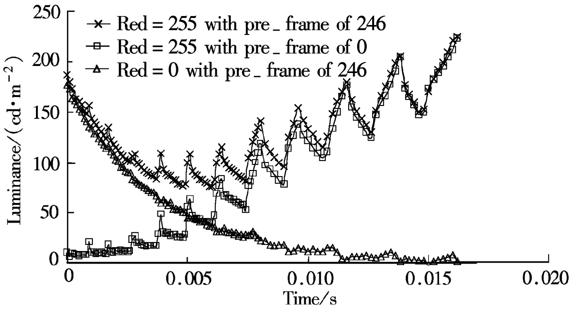

Fig. 6 Luminance curves for different stimulating sequences ($F_v = 60$ Hz)

In Fig. 7, the decay contribution is indicated for pixel $i-2$, and this light will affect the pixels $j-1, j-2, j-3$, and so on. That is, the light of pixel i affects more pixels than indicated in Figs. 4 and 5. The updated segments dividing method is presented in Fig. 7. The phosphor decay effect can be easily included. So with increasing phosphor decay time, the wider the light signal will spread.

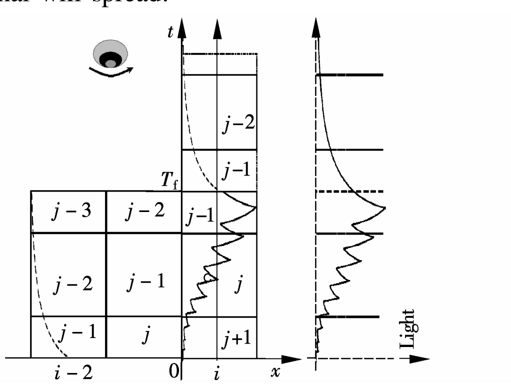

Fig. 7 Simulation principle with consideration of phosphor decay

Now the motion artifact simulation presented in Fig. 3 is fulfilled. The simulation result, for a given motion speed, is represented in a picture $P(k, l)$ with the same size and resolution as the original still one $P_0(m, n)$.

3 Perceptual Evaluation

We did a set of experiments to evaluate if the predicted still image with the motion artifacts shows a good correspondence with motion artifacts in the actually moving image. The two images P and P_0 are displayed on the same screen (see Fig. 8). The above one is the original still picture, which is moving with a user adjustable speed. The bottom one is the predicted image with the motion artifacts that are simulated for a certain motion speed. This bottom image remains still.

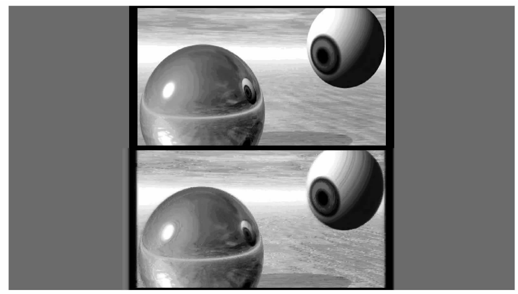

Fig. 8 Image eyeball, used for the perception experiment

The participant controls the motion speed of the above picture and adjusts the speed until he/she thinks the two images match best. Then, at the selected speed, he/she indicates how well the two images match. The 5-point quality scale is used to express the degree of matching: ⑤ Excellent match/identical; ④ Good match/slightly different; ③ Fair match/different; ② Poor match/very different; ① Bad match/completely different.

In total, 21 stimuli (three different testing patterns with different motion speeds) were used in the experiments. Fig. 8 shows the image eyeball. 13 people participated in the experiments. Fig. 9 and Tab. 1 show the average results of the experiment. The following conclusions can be drawn:

1) The speeds chosen by the participants are always around the speed used for simulation (see Fig. 9). The average standard error in the mean is 0.27. So different motion speeds will result in different motion artifacts. People can distinguish them. The simulation model can also differentiate them.

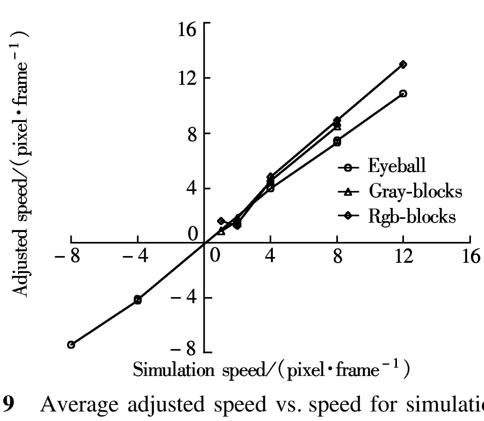

Fig. 9 Average adjusted speed vs. speed for simulation

Tab. 1 Subjective experiment results for picture of eyeball with different motion speeds (see Fig. 8)

Motion speed for simulation v/(pixel·frame^{-1})	8	4	−4	12	−8	−4	8
Average speed chosen by observers/(pixel·frame^{-1})	7.5	4.0	−4.1	10.8	−7.4	−4.2	7.3
Standard error in the mean of the speed chosen by observers	0.32	0.17	0.20	0.24	0.25	0.24	0.35
Average of corresponding score given by observers	4.1	4.5	4.5	4.3	4.3	4.5	4.1
Standard error in the mean of the score given by observers	0.23	0.17	0.19	0.16	0.17	0.16	0.17

Note: Correlation coefficient is 0.999 3 (between the 1st and 2nd row); average matching score over all conditions with different testing speeds is 4.3.

2) The average scores given by subjects are always higher than 4. So the simulation gives a really good prediction of motion artifacts that matches the actual perception results very well.

4 Conclusion

This paper introduces a fast simulation method. It can provide a good prediction of motion artifacts that will become visible on PDPs. The simulation results are validated with perceptual evaluation experiments. This simulation method can be used to compare the performances of different plasma display panels and different driving methods.

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等离子显示中运动伪像的准确估计

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摘要:针对目前等离子显示屏普遍存在的运动伪像问题,提出了一种新颖的模拟计算方法,该方法实现了对等离子体显示屏运动伪像的准确、快速估计. 该方法通过测量等离子显示屏不同颜色不同灰度下光信号随时间的变化情况,仿真人眼对运动图像的视觉感知行为,模拟计算出任意图像以一定速度运动下的视觉感知效果. 新算法不但加入了等离子显示屏荧光粉的延迟效应的影响,而且提高了模拟计算速度. 所得模拟结果与实际主观视觉感知实验相符. 这种快速准确的估计使对等离子显示器件运动伪像的客观评价成为可能.

关键词:等离子显示;运动伪像;动态伪轮廓;运动模糊
中图分类号:TN27