Display Signal Flicker Visibility Analysis

Yancheng Cai https://caiyancheng.github.io/

Abstract

This paper first reviews recent typical methods for measuring flicker visibility of display signals, and then performs flicker visibility analysis for the provided real time-luminance data. Finally, the paper discusses the experimental results and points out possible future research directions.

1. Introduction and Related work

Time-varying light signals are seen by the human eye as flickers, *i.e.* "impressions of unsteadiness of visual perception induced by a light stimulus whose luminance or spectral distribution fluctuates with time" (CIE, 2011, term 17-443). These temporal visual changes can stimulate a high degree of human attention, especially flickering at a frequency of around 10 Hz. As the flicker frequency increases further, the sensitivity of the human visual system gradually decreases, tending to 0 at about 60 Hz. This sensitivity-frequency relationship is approximated by the temporal contrast sensitivity function (TCSF) function [12].

Researchers have attempted to predict flicker perception based on measured temporal changes in display brightness.

ISO 9241-3: 1992 [1] outlines two analytical techniques for predicting screen flickering based on D. H. Kelley's experimental results [3, 4]. The first method uses the phosphor decay time constant and average screen luminance of a monochrome CRT to determine if flicker is perceived by comparing the retinal illuminance value to a threshold dependent on display size. The second method determines the minimum refresh rate for a flicker-free display under specified viewing conditions. Both methods are applicable only to CRT-based displays that assume an exponential decay in brightness during progressive scanning.

ISO 13406-2:2001 [6] outlines a method for evaluating the frequency components of modulated screen luminance up to 120 Hz through high-speed luminance sampling and discrete Fourier transformation procedures. Threshold values are determined for each frequency component based on a list of parameters for four classes of visual angles, determined by the size of the display being tested. However, there have been reports of conflicting results between predicted "flicker" and actual visual experience in many cases.

Further Work In 1997, Sidebottom [7] adapted Farrell's model to realistic observation conditions, successfully applying it to LCD-monitors with PMW controlled backlight units, which can cause large-area flicker [9]. By optimizing screen driving conditions, such as frame rate and single/double pulse mode, the authors established a good match between model predictions and perception experiments. Their findings indicate that the CFF values, calculated with the model developed for CRTs, are reliable for predicting perceived flicker in scanning-backlight LCDs. A method was introduced in 2011 for predicting display flicker perception in terms of just noticeable differences (JNDs) [10], with initial limitations later resolved in a follow-up paper [11]. This approach is now presented in 10.6 - Flicker visibility - IDMS:2012 [5].

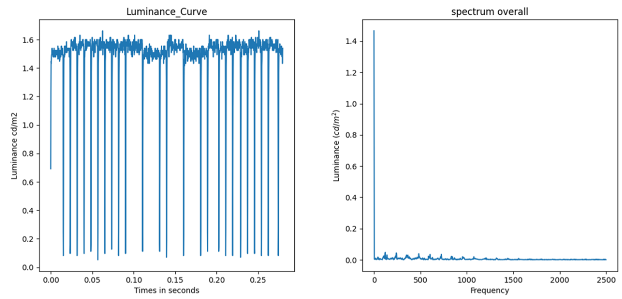

Figure 1. The luminance-time waveform is accompanied by a discrete Fourier transform (DFT) spectrogram. Notably, the DFT is divided by the sample size, rather than the square root of the sample size as stated in the IDMS material. This correction is necessary due to several inconsistencies in the IDMS material, as explained in my supplementary material.

Frequency (Hz)	0	17.86	42.86	53.57	121.43
DFT amplitude (cd/m^2)	1.4662	0.0105	0.0178	0.0098	0.0475
TCSF	-	92.084	6.5040	1.7513	0.0007

Table 1. Some peaks in the sub-120Hz part of the DFT. Flicker at frequencies above 120Hz is barely detectable by the human visual system.

2. Data Analysis and Experiments

We visualize the luminance-time waveform and calculate the DFT spectrum (Figure 1 and Table 1). In the rest of this section, we first present the results of some existing methods, and then propose my own methods.

JNDs method [10] is the standard method provided in IDMS:2012 [5]. However, it requires a fixed fundamental frequency and assumes high-frequency flickers have low energy, which is not applicable. I only consider 17.86 Hz flickers because 120 Hz flickers are almost invisible.

$$C_R = 2 \cdot |\tilde{K}_{N_f}|/\bar{K} = 2 \cdot 0.0105/1.4662 = 0.0143 \quad (1)$$

$$S = TCSF(17.86) = 92.084 \quad (2)$$

$$J = S \cdot C_R = 1.3225 \quad (3)$$

All the symbols above are the same as in IDMS. However, it is unreasonable to assume a single fundamental frequency.

FMA method [8] (Flicker Modulation Amplitude) measures the flicker rate of a display screen by calculating its brightness modulation amplitude over time:

$$\text{FMA} = \frac{2\,(L_{\max} - L_{\min})}{L_{\max} + L_{\min}} \times 100\% = 187.8\% \quad (4)$$

This method disregards the fact that flicker perception is linked to the periodic alteration of luminance signals and does not account for the varying sensitivities of the human eye to different frequencies.

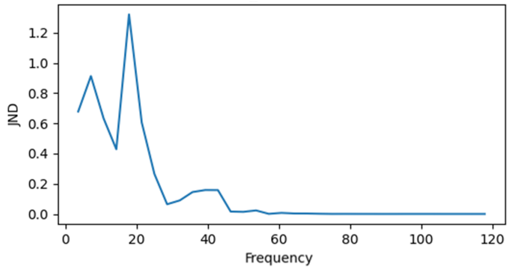

Figure 2. The JND-frequency curve takes into account all fundamental frequencies less than 120Hz.

JEITA method is the standard method stipulated by the Japan Electronics and Information Technology Industry Association, an improved version of the JNDs method. It multiplies the amplitude of each DFT frequency by the sensitivity factor at the corresponding frequency of the TCSF curve to find the maximum amplitude P_{max}, and calculate the flicker rate according to the following formula:

$$\text{JEITA} = 10 \cdot log_{10}(\frac{P_{max}}{\tilde{K}_0}) = -1.7965 \tag{5}$$

VESA method, defined by the Video Electronics Standards Association, shares the same test steps as the JEITA method. The only difference lies in its calculation formula:

$$\text{VESA} = 20 \cdot log_{10}(\frac{2P_{max}}{\tilde{K}_0}) = 2.4277 \tag{6}$$

My method 1 – Max Flicker Visibility is based on the JNDs method, but considers all possible flicker frequencies and finds the max JND at each frequency. Specifically, $\tilde{K}_f$, $J(f)$ is computed for each frequency f (Figure 2):

$$J(f) = S \cdot C_R = TCSF(f) \cdot 2|\tilde{K}_f|/\bar{K} \tag{7}$$

$$\text{JND}_{max} = max(J(f)) = 1.3225 \tag{8}$$

My method 2 – Quadrature Amplitude Combination Borrowing the idea from [2], The JND components at different frequencies are considered to be perceptually independent of each other in the same way that the Fourier frequency components of a waveform are mathematically independent of, or orthogonal to, one another. Just as the total power of a complex waveform is calculated as the square root of the sum of the squares of the component power values, the total flicker visibility is calculated as:

$$\text{JND}_{combine} = (\sum_f J(f)^2)^{\frac{1}{2}} = 2.0377 \tag{9}$$

3. Further Thoughts

Illuminance-dependent TCSF In fact, the sensitivity of the human visual system to flicker is not only related to the flicker frequency, but also related to the luminous flux (retinal illuminance) irradiated into the human eye. Referring to the conclusion in [11], I made a figure of the 2D TCSF surface, as shown in Figure 3. Note that the accuracy of this surface has yet to be verified experimentally.

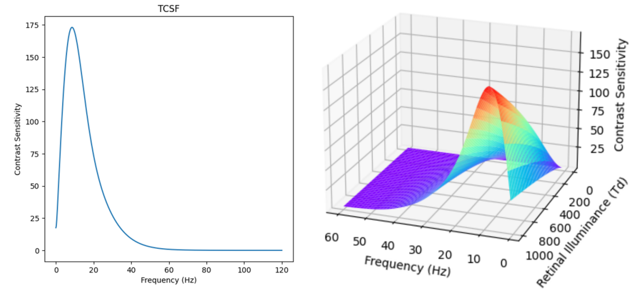

Figure 3. Left: Standard TCSF curve under illuminance of 1000 Td. Right: 2D TCSF surface with illuminance as a variable.

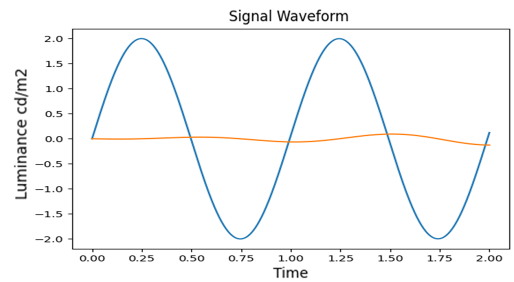

Figure 4. Both signals have the same DFT amplitude but different phase maps. $f_1 = sin(2\pi) + sin(2.02\pi)$; $f_2 = sin(2\pi) + sin(2.02\pi + \pi)$

Considering the influence of illumination, my methods can be expressed by the following formula:

$$J(f) = S \cdot C_R = TCSF(f, \bar{K}) \cdot 2|\tilde{K}_f|/\bar{K} \tag{10}$$

$$\text{JND}_{max} = max(J(f)) = 1.2159 \tag{11}$$

$$\text{JND}_{sum} = (\sum_f J(f)^2)^{\frac{1}{2}} = 1.8728 \tag{12}$$

where I assume that the maximum value in the luminance-time waveform corresponds to 1000 Td retinal illuminance. It may not be correct, here is just an example.

DFT phase map Almost all DFT-based methods use only amplitude maps. It is appropriate when only a single fundamental frequency is considered. However, using pure amplitudes may not be appropriate in some cases when more fundamental frequencies are used (Figure 4). Although the flicker visibility of both signals is the same for an infinite time, humans can only perceive flicker for a finite time. For a limited time, the flicker visibility of signal 1 should be significantly greater than that of signal 2.

More Influencing Factors The methods mentioned above are not influenced by the display characteristics and are solely relevant to the signal waveform. Although these methods are simple to implement, they do not provide comprehensive guidance for display design. It is worth noting that flicker visibility is also affected by varying conditions, including but not limited to: (1) diverse viewing conditions, such as the level of illumination, field of view size, and the position in the field of view (direct or edge view); and (2) individual and group differences among viewers. Due to the distinct hardware configurations, usage environments, and user preferences associated with different displays, it is crucial to make display-specific adjustments when assessing flicker visibility.

References

[1] ISO 9241-3. Ergonomic requirements for office work with visual display terminals (vdts)–part 3: Visual display requirements, 1992. 1

[2] D Bodington, A Bierman, and N Narendran. A flicker perception metric. *Lighting Research & Technology*, 48(5):624–641, 2016. 2

[3] JE Farrell, Brian L Benson, and Carl R Haynie. Predicting flicker thresholds for video display terminals. In *Proc. SID*, volume 28, pages 449–453. Citeseer, 1987. 1

[4] Joyce E Farrell. An analytical method for predicting perceived flicker. *Behaviour & Information Technology*, 5(4):349–358, 1986. 1

[5] International Committee for Display Metrology. Information display measurements standard. *Society for Information Display (SID)*, 135, 2012. 1

[6] ISO. Ergonomic requirements for work with visual displays based on flat panels—part 2: Ergonomic requirements for flat panel displays, 2001. 1

[7] Shane D Sidebottom. *Effects of Illumination and Viewing Angle on the Modeling of Flicker Perception in CRT Displays*. PhD thesis, Virginia Tech, 1997. 1

[8] Peter Thompson and Leland S Stone. Contrast affects flicker and speed perception differently. *Vision research*, 37(10):1255–1260, 1997. 1

[9] Lili Wang, Kees Teunissen, Yan Tu, and Li Chen. Flicker visibility in scanning-backlight displays. *Journal of the Society for Information Display*, 16(2):375–381, 2008. 1

[10] Andrew B Watson and Albert J Ahumada. 64.3: flicker visibility: a perceptual metric for display flicker. In *SID symposium digest of Technical Papers*, volume 42, pages 957–959. Wiley Online Library, 2011. 1

[11] Andrew B Watson and Albert J Ahumada. 5.3: Extending the flicker visibility metric to a range of mean luminance. In *SID Symposium Digest of Technical Papers*, volume 46, pages 30–32. Wiley Online Library, 2015. 1, 2

[12] Andrew B Watson et al. Temporal sensitivity. *Handbook of perception and human performance*, 1(6):1–43, 1986. 1