Second-order vision requires second-order calibration

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What is second-order vision?

A. First-order - Luminance-modulated (LM) noise

First-order variation have distinct Fourier components

B. Second-order - Contrast-modulated (CM) noise

Second-order variations do not have distinct Fourier components

C. Nonlinearity,introduces LM into CM noise

First-order introduced in second-order by a non-linear transformation

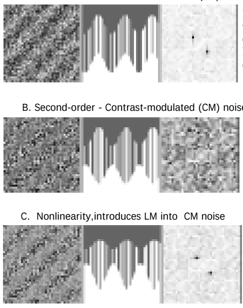


Image Profile Fourier spectrum

Human vision can detect both 1st-order variations in luminance and 2nd-order variations in contrast.

BUT

It is easy to produce 1st-order artefacts from 2nd-order stimuli.

Two important sources of 1st-order artefact have been explored.
1) The Adjacent Pixel Non-Linearity (APNL).
2) DC biases (Clumps) in the image itself.

FORTUNATELY
These artefacts are easily avoided!

Simple calibration guidelines

Adjacent Pixel Non-Linearity

Choose a good screen with high bandwidth.
Set it up for minimum gamma.
Correct gamma as normal.
Use low contrast if possible
Limit maximum resolution to avoid high frequencies.

Local DC Biases

Ensure that you have at least 4 noise patches per period of the modulating signal.

References

Klein, S.A., Hu, Q.J., Carney, T. (1996). The adjacent pixel nonlinearity: prolems and solutions Vision Research 36, 3167-3181

Mulligan,J.B., & Stone, L.S. (1989) Halftoning method for the generation of motion stimuli. J. Opt. Spc. Am. A, 6, 1217-1227.

Smith, A.T.,& Ledgeway, T. (1997). Separate detection of moving luminance and contrast modulations: fact or artefact. Vision research 37, 45-62.

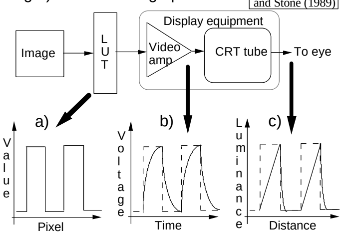
1) The Adjacent Pixel Non-Linearity (APNL)

Problem

The luminance of a pixel is dependent upon the luminances of adjacent pixels.

Cause

Fig 1) Model of image production Due to Mulligan and Stone (1989)



a) High frequency image variations after gamma correction.
b) Bandwidth limitations in the video amplifier smooth the waveform.
c) Rising and falling edges are distorted by gamma transformation.

APNL is only a problem for signals that vary along the direction of travel of the electron beam. (That is across the raster of a raster scan screen)
APNL is worst when:

- Image contrast is high.
- Screen gamma is high.
- Video bandwidth is low.

2) Consequences

1) High frequency image components are attenuated.

2) Mean luminance is reduced in high frequency, high contrast images.

3) On a raster screen - vertical edges, lines or gratings will have a lower contrast and mean luminance than their horizontal counterparts.

4) Second-order contrast variations of high resolution carriers will produce first-order variations in mean luminance.

Description	Image	Mean luminance
12.8 c/cm Horizontal squarewave grating		59.2 cdm^{-2}
12.8 c/cmVertical squarewave grating		48.5 cdm^{-2}
1.5mm wide horizontal white line on black background		7.0 cdm^{-2} at 1.7m (Averaged over RF of meter)
1.5mm wide vertical white line on black background		5.9 cdm^{-2} at 1.7 m (Averaged over RF of meter)
Low contrast noise		← 57 cdm^{-2}
High contrast noise		← 53 cdm^{-2}

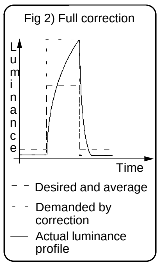
Monitor = EIZO 6500-M (γ=1.8, BW≈120MHz) Luminance meter = Minolta LM-110

3) Solutions

Full correction

Klein, Hu, and Carney (1996) have presented a method which fully corrects APNL. The error at any point on the screen depends on size and direction of the transition between adjacent pixels. Thus the error depends on both the current pixel value and the preceding pixel value. By modelling the dynamics of the screen and its gamma error it is possible to work out a correction factor for all pairs of pixel values. The image can then be calibrated against both APNL and gamma using these corrected values. Unfortunately this (pixel by pixel) correction is relatively time consuming and would not be appropriate when image contrast was varied from frame to frame or trial to trial.(See Fig 2)

Fig 2) Full correction



Simple method

The effects of APNL can be minimised by careful calibration and the avoidance of very high frequency image components:

1) Purchase a good monitor with high video bandwidth.
2) Minimise gamma by choosing appropriate brightness and contrast settings.
3) Correct gamma as normal.
4) Where possible the maximum contrast to be displayed should be limited.
5) Measure the mean luminance of a number of images at different contrasts. The images should reflect those that are to be used in experiments. (eg for experiments with contrast modulated noise one would test with noise fields of different resolutions.
6) The highest resolution that gives no reduction in mean luminance with increase contrast should be chosen as the maximum resolution for experimentation.

Example calibration

(using the simple method)

1) Monitor specification
Ezio Flexiscan 6500-M
Video bandwidth ≈ 120MHz

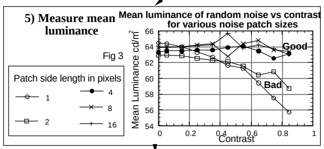
2) Gamma minimisation
Gamma = 1.8 when,
Lmin=5.6 cdm^{-2}
Lmax=129 cdm^{-2}

3) Gamma correction
Using inverse transform in look-up-table.

4) Maximum contrast
91% from Lmin and Lmax

5) Measure mean luminance

Fig 3

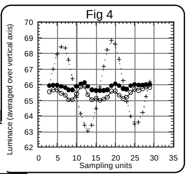


6) Chosen resolution:
Minimum side length of noise patch = 4 screen pixels

Verification

Fig 4 shows the luminance cross section of noise, luminance modulated noise and contrast modulated noise. The luminance variation in the CM case is minimal and mimics the variation in the noise

Fig 4

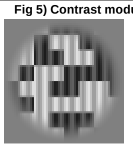


5) Local DC Biases (Clumping)

Problem

Smith and Ledgeway (1997) have noted that visual noise can contain clumps of pixels with identical luminance. These regions or clumps give rise to local DC biases in the image. When clumps are subject to contrast modulations the result is a clearly discernible variation in the localised luminance profile. Figure 5 shows an exaggerated example of this where the noise samples have been made excessively large.

Fig 5) Contrast modulated low resolution noise



Local variations in luminance are seen clearly in this example where the noise has very low resolution.

Solutions

Clumping is only a problem when visual noise is used as a carrier for second order signals, however, this carrier type is very useful and the existence of clumping causes difficulties. Smith and Ledgeway (1997) propose two solutions to the clumping problem: High pass filtering and dynamic noise. High pass filtering removes all DC from the image, setting the luminance of clumps to the mean luminance level. Dynamic noise removes the effects of clumping by constantly varying the noise sample presented.

BUT:
The results show in panel 6 indicate that clumping is not a problem for noise carriers with a resolution that is likely to be used in experimentation.

6) Modelling the effects of clumping

Luminance and contrast modulated noise samples with different noise patch side lengths were applied to a simple model of first-order detection (see Fig 6). This model comprised two quadrature phase Gabor filters whose output were combined to form a first order energy response. The spatial parameters of the filters were set such that their bandwidths were close to those of physiological mechanisms (about 1.8 octaves). The preferred frequency of the filters was set equal to the modulation frequency.

Fig 6) First-order model

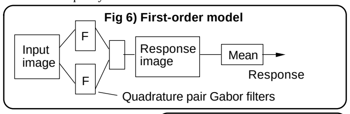
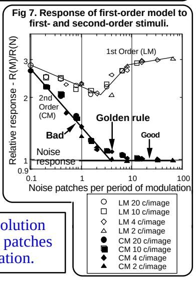


Fig 7 shows the response of the first-order model to luminance and contrast modulations (of various frequencies) relative to its response to noise alone. The response to the CM noise is equivalent to that of noise alone so long as there are at least 4 noise patches per period of modulation. If the number of patches per period is reduced the response of the model to CM increases toward that for LM, demonstrating the effects of clumping.

Fig 7. Response of first-order model to first- and second-order stimuli.



Golden rule: Noise resolution must not be less than 4 patches per period of modulation.