Uniformity: Imatest Master Features

This section describes ***Uniformity*** (formerly ***Light Falloff***) features available with Imatest Master, Image sensor, and other full-strength versions of Imatest, i.e. not available in Studio. ***Uniformity*** was originally intended to measure lens vignetting (the falloff in illumination at the edges of the image), but it can measure a variety of image nonuniformities— resulting from the lens, illumination, or sensor— including color shading, noise distribution, and spots from dust (though the Blemish Detect module is much better at handling spots). Basic instructions are found in Using Uniformity.

New in Imatest 3.9 The Extra smoothing checkbox in the settings window makes contour and color shading plots smoother and easier to interpret.

New in Imatest 3.6 Uniformity-Interactive is an interactive module that duplicates Uniformity's functionality. It is compatible with the Imatest Image Sensor edition.

Input dialog box

The following settings are available in all Imatest versions:

- **Title** Defaults to the file name. You can change it if you wish.
- **Display Uniformity contour plots** (**Plot** area; on by default).
  Turns the main light falloff contour plots off or on. Normally on (checked), but may be turned off by Imatest Master users interested in other results, such as hot/dead pixels and color shading. Four display options are available. Normalized refers to the first (level) plot only.
  Examples on Using Uniformity.

Contours superposed on image (not normalized)
Contours superposed on image (normalized to 1)
Pseudocolor with colorbar (not normalized)
Pseudocolor with colorbar (normalized to 1)

- **Speedup** When checked, several results (those that require significant calculation time) are not calculated (and hence not saved in the CSV output file) if the corresponding plot is not selected. This can save significant time in production environments. If you need to use **Speedup**, you should run Uniformity with and without Speedup checked and examine the CSV output file to see if it contains the results you require.

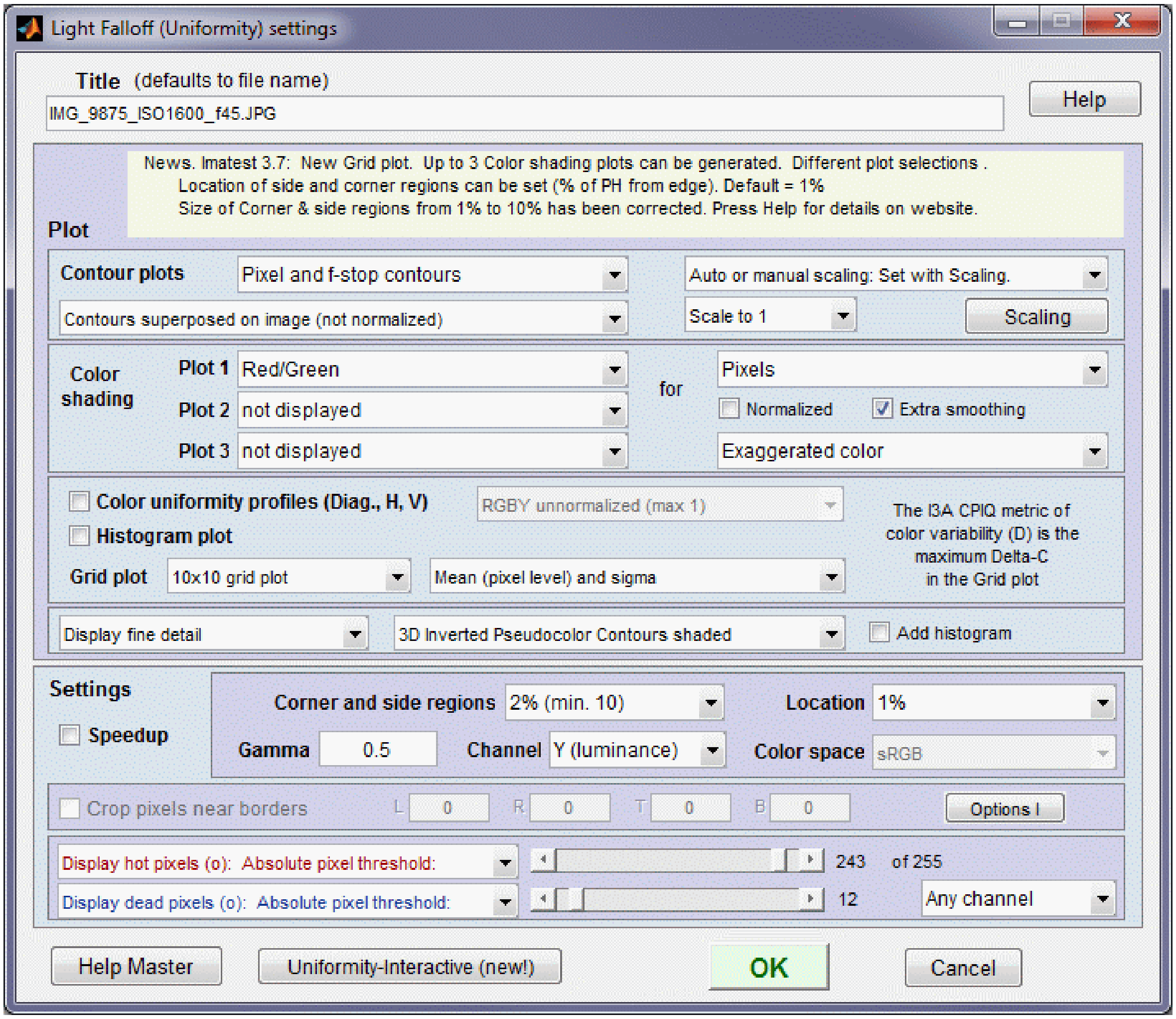
- **Gamma** The default value of gamma, 0.5, is typical for digital cameras. Gamma affects only the second figure (the light falloff measured in f-stops); it has no effect on the first figure. Gamma can be measured by Stepchart using any one of several widely-available step charts. (Reflection charts are easiest to use but transmission charts can also be used to measure dynamic range.) Some issues in calculating gamma are discussed below the second figure.

- **Corner and side regions** (default 32x32 pixels) allows you to select the areas at the corners and sides of the images to be analyzed. Choices include 10x10 pixels, 32x32 pixels, 1% (min. 10x10), 2% (min. 10x10), 5%, and 10%. These regions can be used as the reference for the Color shading ΔE and ΔC calculations.

- **Crop pixels near borders (L, R, T, B)** (**Settings** area). If checked, the image is cropped by the number of pixels indicated near the left, right, top, and bottom borders. Several cropping (ROI selection) options are available by clicking Settings, Options and Settings… in the Imatest main window. These incluce

Don’t ask to crop. (Use settings in LF input dialog box.)
Select crop by dragging cursor. Ask to repeat crop for same sized image.
Select crop by dragging cursor. Do not ask to repeat crop.

Although the first option (**Don’t ask to crop…**) was the default prior to Imatest 2.3.12, the second option (**Select crop by dragging cursor. Ask to repeat crop for same sized image**), which is similar to the ROI selection in SFR, may be preferred.



Uniformity input dialog box (for Master).

The following options are available in Imatest Master only:

- **Color shading (nonuniformity)** Display the color nonuniformity, i.e., the difference between two of the three (R, G, B) channels or one of the L*a*b* color difference metrics ($\Delta E = \text{sqrt}(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})$, $\Delta C = \text{sqrt}(\Delta a^{*2} + \Delta b^{*2})$, ΔE_{94}, ΔC_{94}, ΔE_{00}, ΔC_{00}), referred to the center of the image (either the central region, with size specified in the **Corner and side regions** box or the central 25% by area). Color shading often results from the angle at which light strikes the sensor. It tends to be worst in tiny pixels. Several options are available.
  - **Color shading** Select not displayed (turns off plot), Red/Blue, Red/Green, Green/Blue, or ΔE or ΔC (various flavors & reference regions). Red/Blue (the extremes of the spectrum) is the most popular choice for displaying shading. **for (plot units).** To the right of the Color shading box. Select Pixels (gamma-encoded), Intensity (linear), or f-stop difference. Grayed out if ΔE or ΔC metrics are selected.

Pixels	Displays the ratio of the the pixel values for the selected channels. If Normalized is checked, the plot is normalized to 1.0 (maximum).

Intensity (linear)	Removes the gamma encoding of the image file using the value of Gamma entered and displays the ratio of the intensities for the selected channels. If Normalized is checked, the plot is normalized to 1.0 (maximum).
F-stop	Displays the f-stop difference between the selected channels. If Normalized is checked, the plot is normalized to 0 (maximum).

- **Display** Select the display type. Four choices.

Examples are shown below

Exaggerated color	2D. Increases the color saturation to increase the visibility of color nonuniformities.
Pseudocolor	2D
3D Pseudocolor, shaded, auto-scaled.	Shading emphasizes contour shapes.
3D Pseudocolor, auto-scaled.	

- **Normalized** (Checkbox) If checked (the default), the shading plot is normalized to a maximum of 1 for pixels or intensity (linear) or 0 for f-stop difference. The unnormalized maximum and minimum values are displayed beneath the plot.

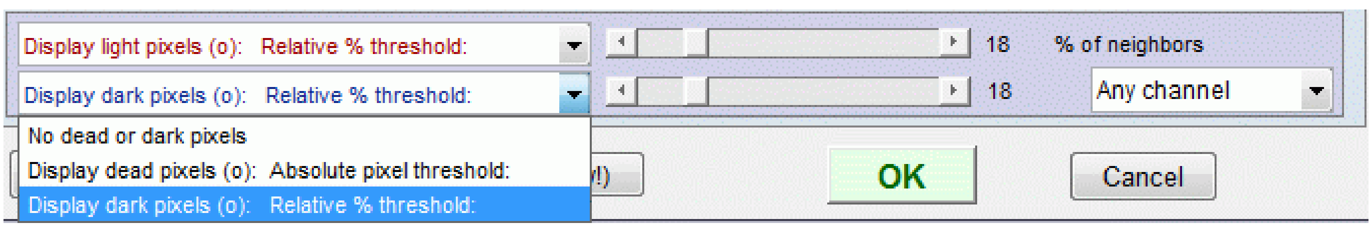
- **Display color uniformity profiles** Shows pixel levels along diagonal, vertical, and horizontal lines. The specific display is selected in the dropdown menu on the right. Described below.
- **Display histograms** Useful in diagnosing stuck (hot and dead) pixels. Described below.
- **Display fine detail** Display a detailed image of noise and sensor nonuniformity (examples below). Slow variations in image density— vignetting (low spatial frequencies) — are removed so that only short to medium range variations— sensor noise, dust spots, etc.— remain. The calculation can be slow and uses ***lots***of memory because Matlab calculations are performed in double precision mathematics, which requires 24 bytes per color pixel (8 bytes per channel).

Exaggerated local noise (standard)

Local noise with added contours
Pseudocolor contours with colorbar
Spot detection w / threshold (pseudocolor)
(Several additional 3D displays)

Several display options are available. The first displays noise exaggerated by a factor of 10. The second superposes contour plots (from a smoothed version of the image) on the noisy image. The third produces a pseudocolor image of local nonuniformities (also smoothed) with a color bar (legend) on the right. The fourth emphasizes dark spots, usually caused by dust. A histogram can also be added beneath the fine detail plot.

- **Channel** You can choose between Red, Blue, Green, or Y (luminance) channels. **Color space** Used for converting from RGB color space where L*a*b* color difference metrics are displayed.
- **Hot and dead pixels** By checking the appropriate boxes you can display hot or light pixels (**red x**) and/or dead or dark pixels (**blue •**).



The definition depends on whether **Absolute pixel threshold** or **Relative % threshold** is selected:

Display hot or dead pixels (o): Absolute pixel threshold
Hot pixels are stuck at the sensor's maximum value (255 in 8-bit files) and dead pixels are stuck at 0. Because signal processing— especially JPEG compression— often causes these values to shift, you can use the sliders to set the detection threshold between 6-255 for hot pixels and 0-249 pixels for dead pixels. (The extreme values are for measurements made on white or black fields.) Clicking on or at the ends of the sliders adjusts the threshold by 1. The default values are 252 and 4, respectively.
Display light or dark pixels (o): Relative % threshold

Light pixels are more than the relative % threshold above the mean of the 8 neighbors;
Dark pixels are more than the relative % threshold below the mean of the 8 neighbors.

JPEG files should be saved at the highest quality level for this feature to work well; isolated hot and dead pixels tend to be smudged at lower quality levels. Details of hot and dead pixels are presented below. You can choose whether to count a pixel as hot or dead (light or dark) if the criteria are met by **any color channel** (the default), **all channels**, or the **selected channel**.

Results

Hot and dead pixels (Imatest Master only)

2 hot, 2 dead pixels
of 8185344 total
Threshold: h= 245; d= 10

Imatest Master allows you to detect hot and dead pixels. Hot pixels are stuck at or near the sensor's maximum value (255 in 8-bit files); dead pixels are stuck at or near 0. Image processing (especially demosaicing and data compression) may alter these numbers. Thresholds lower than 255 and higher than 0 are usually required, particularly for JPEG files, where isolated pixels are smeared, even for the highest quality levels. Hot and dead pixels cannot be reliably detected in JPEGs saved at lower quality levels.

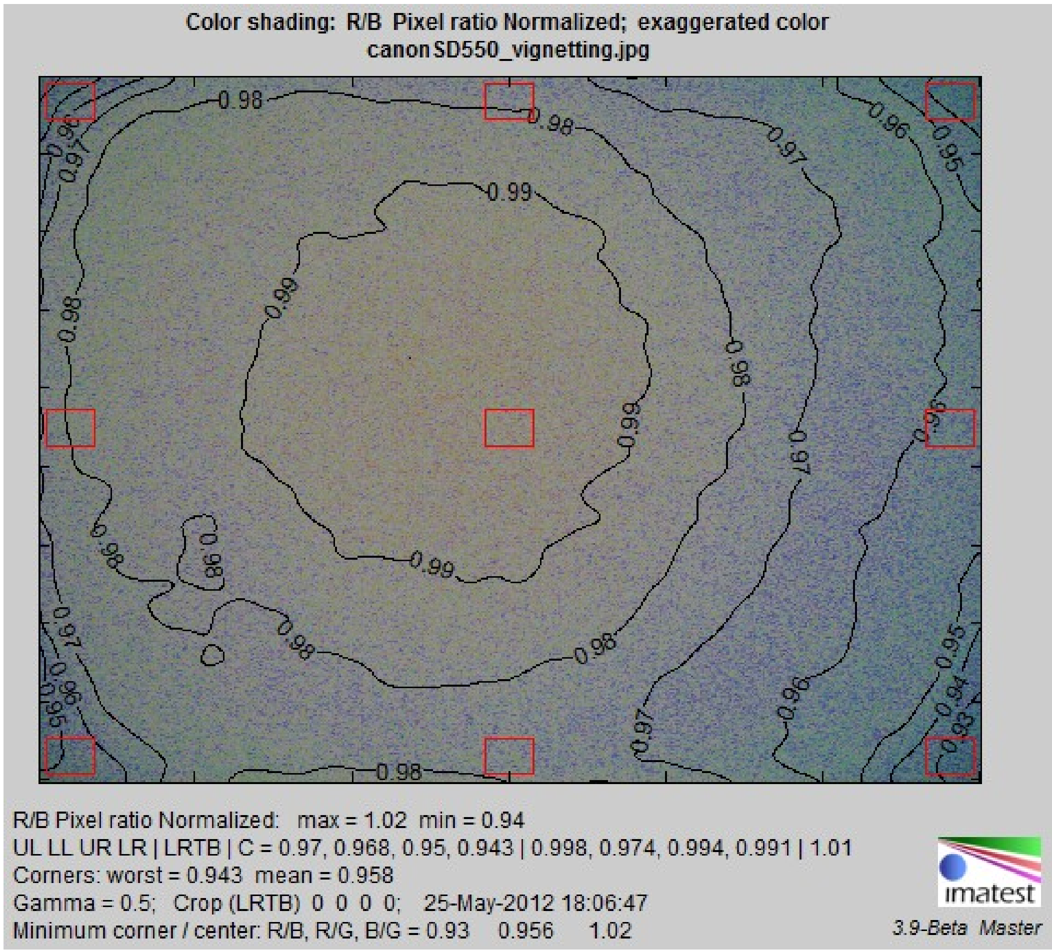
	A	B	C	D
15				
16	Hot/dead pixel analysis			
17	Image pixels	3504	2336	8185344
18	Hot threshold	245		
19	Hot pixels	2	2.44E-07	
20	1	1713	1148	
21	2	3295	2200	
22	Dead threshold	10		
23	Dead pixels	2	2.44E-07	
24	1	1860	1249	
25	2	3416	2281	
26				

The hot and dead pixels shown on the right met the criteria that they were above or below the threshold for *any* color channel. All channels or the selected channel could have been selected.

The first figure in Uniformity shows two simulated hot (**x**) and dead (•) pixels. The CSV output file on the right shows the basic statistics for the image (8185344 pixels total). h = 245 and d = 10 are the hot and dead pixel thresholds, respectively. The number and fraction of the hot and dead pixels are shown, followed by the x and y-locations of the first 100 hot and dead pixels. The Histogram plot, described below, is useful for selecting thresholds.

Color shading (nonuniformity) (Imatest Master only)

The Color shading plot displays the ratio or difference between R, G, and B channels or L*a*b* color differences (ΔE, ΔC, ΔE_{94}, ΔC_{94}, ΔE_{00}, or ΔC_{00}). Two examples are illustrated below. The first shows shading as the ratio of Red to Blue (R/B) channel pixels. Plotted results have been normalized to a maximum of 1.0. Normalization only affects the plots; it makes the plotted results relatively insensitive to white balance errors. The background displays the image with exaggerated colors (HSV saturation S has been increased by 10x for low saturation values; less for high values.)



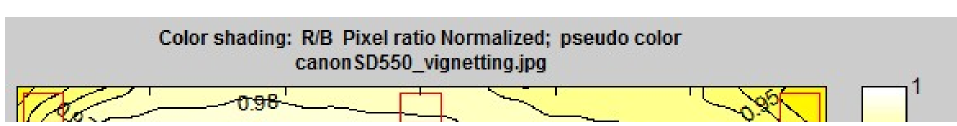
R/B Color shading, exaggerated color.

Normalization refers to the plot-only. The numbers displayed below the plot are not normalized.

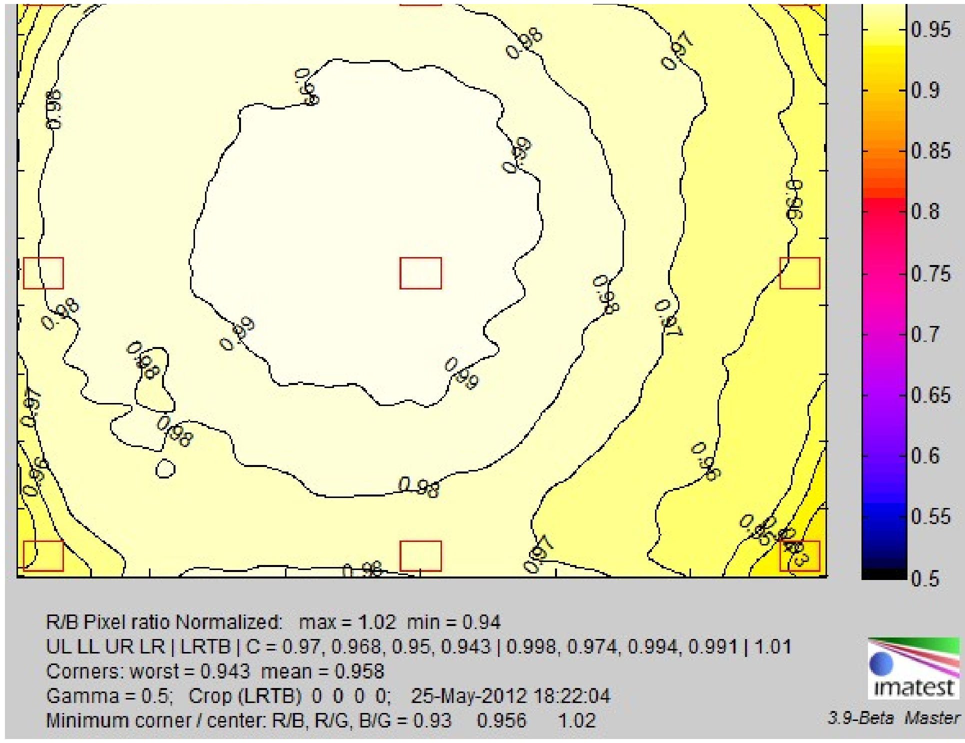
The R/B Pixel ratio max and min (1.02 and 0.94) are taken over the entire smoothed image (not restricted to the corner and side areas indicated by the **red** rectangles). For this reason they tend to be more extreme than the maxima and minima of the squares (displayed on the next line), and the ratio between them (0.94/1.02 = 0.92) is generally lower than the minimum ratio between the center and the sides & corners.

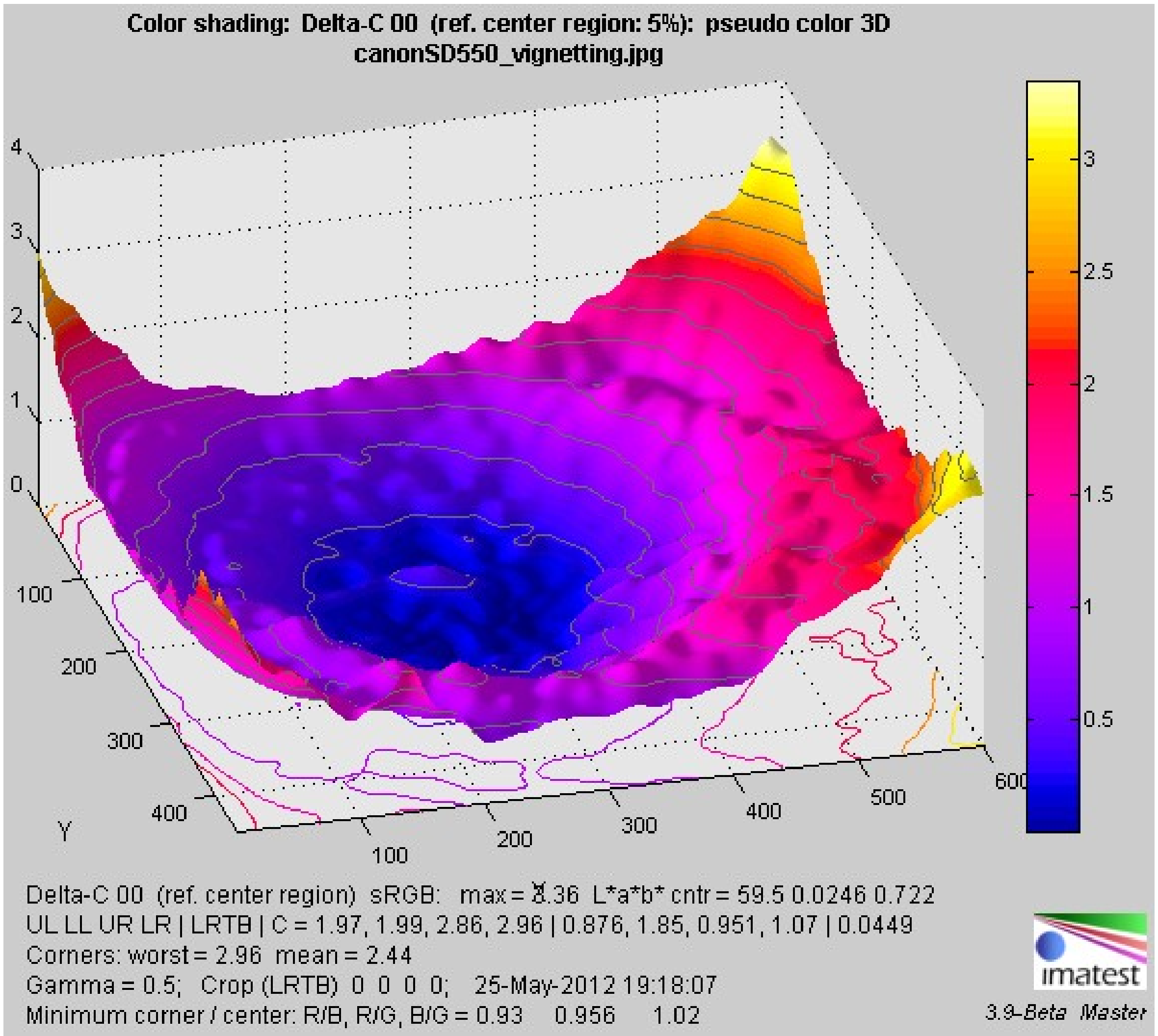
The second example shows the R/B ratio in pseudocolor. (The difference in f-stops could also be displayed, but is not shown here.) Plotted results have been normalized to 1.0.

R/B color shading, pseudocolor.



Color nonuniformity can be displayed as one of the [L*a*b* color difference metrics](#) ($\Delta E = \text{sqrt}(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})$, $\Delta C = \text{sqrt}(\Delta a^{*2} + \Delta b^{*2})$, ΔE_{94}, ΔC_{94}, ΔE_{00}, ΔC_{00}), referred to the center of the image (either the central region, with size specified in the **Corner and side regions** box or the central 25% by area). The ΔC metrics are of particular interest for color metrics because they omit luminance differences (ΔL^*). It is displayed below as a 3D plot, which can be rotated for enhanced visualization..

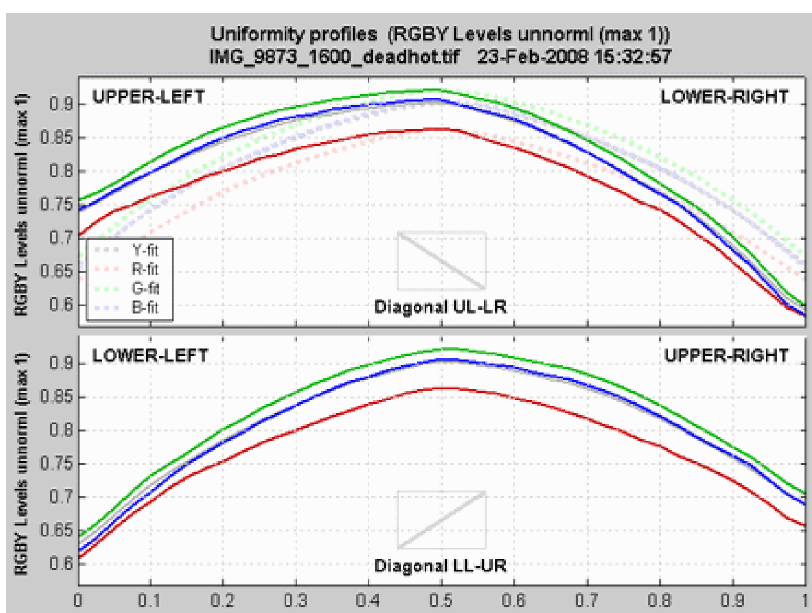




ΔC 2000 color shading (omits ΔL*), 3D shaded pseudocolor.
The Extra smoothing box should *always* be checked for 3D plots.

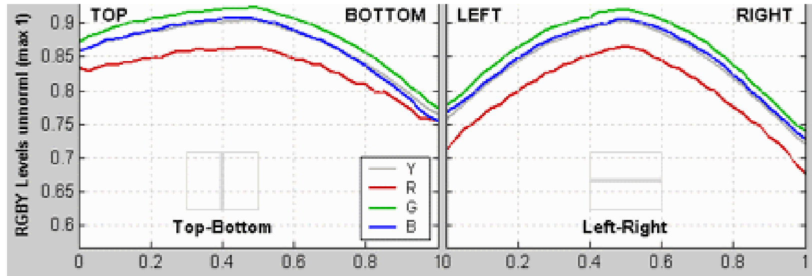
Uniformity profiles (Imatest Master only)

Uniformity profiles.Uniformity profiles displays profiles of image levels along several lines: Diagonal Upper Left-Lower Right, Diagonal Lower Left-Upper Right, Vertical Top-Bottom (center), and Horizontal Left-Right (center). Several display options are listed below.



RGBY unnormalized (max 1)
RGBY unnormalized pixels (max 255)

RGBY normalized (max 1)
Ratios: R/G, B/G (G constant)
RGBY normalized: ALL CHANNELS
Delta L* a* b* C* (C* = chroma)



The independent axis goes from 0 to 1 in steps of 0.025 (41 steps total). Detailed results for the 41 steps are written to the CSV and XML output files.

Polynomial fit A fourth order fit to R, G, B, and Y (or L*, a* and b*) is shown as faint dotted lines in the upper (Diagonal UL-LR) plot. The equation for the fit is

$$y = c_1 r^4 + c_2 r^3 + c_3 r^2 + c_4 r + c_4$$

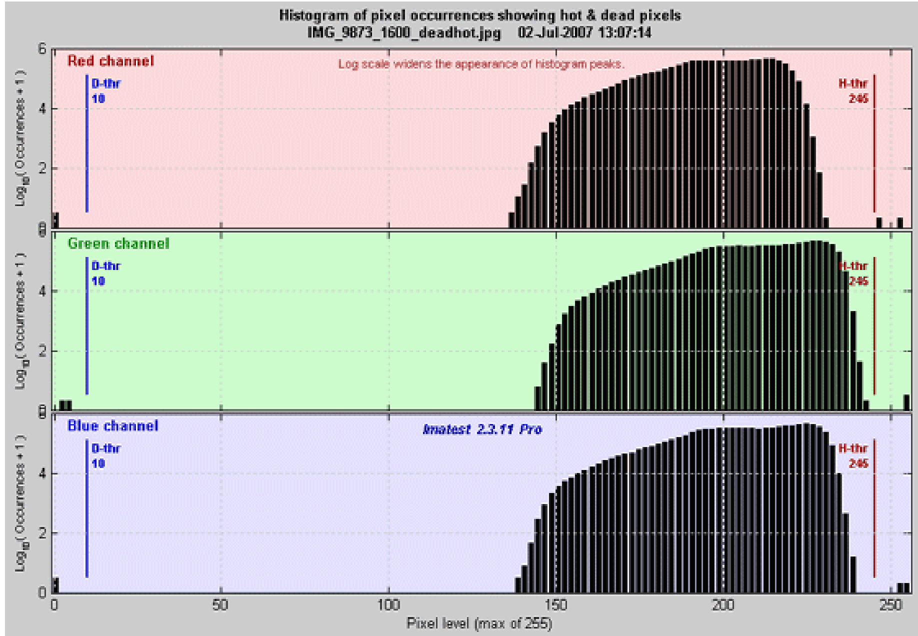
where r is the distance from the center normalized to the center-to-corner distance (r = 1 at the corners). The R, G, B, and Y coefficients are in displayed the CSV and XML output files. There is not enough space to show them in the plot. They have the following format in the CSV output file.

Fourth order fit: y = c(1)*r^4 + C(2)*r^3 + ... + c(5) where r is normalized to center-to-corner.					
R	0.045	-0.108	-0.081	-0.083	0.866
G	-0.124	0.207	-0.295	-0.037	0.922
B	-0.189	0.315	-0.341	-0.037	0.907

Histograms (Imatest Master only)

The histogram plot, introduced in Imatest Master 2.3.11 (July 2007), facilitates the detection and the setting of thresholds for stuck (hot, dead, etc.) pixels. Histograms of $\log_{10}$(occurrences+1) are displayed for the **red**, **green**, and **blue** channels. [The logarithm compresses the plot so even a single bad pixel is visible. $\log_{10}$(occurrences+1) is used because log(0) = −∞ (minus infinity), while log(1) = 0.]

R, G, and B Histograms showing stuck pixels.



In this example, single stuck pixels are plainly visible near levels 0 and 252. Altough these stuck pixels were synthesized, their levels is slightly different due to JPEG compression (they were the same in a TIFF file). The dead pixel threshold is shown on the left in **blue**; the hot pixel threshold is shown on the right in **red**. You can quickly see if the thresholds are set correctly— if they are outside the valid density region and if the dead and hot pixels are above and below their respective thresholds. You can change threshold settings and rerun Uniformity if necessary.

Noise detail (Imatest Master only)

shows an exaggerated or pseudocolor image of the noise detail with long-range density variations removed. Four options are available:

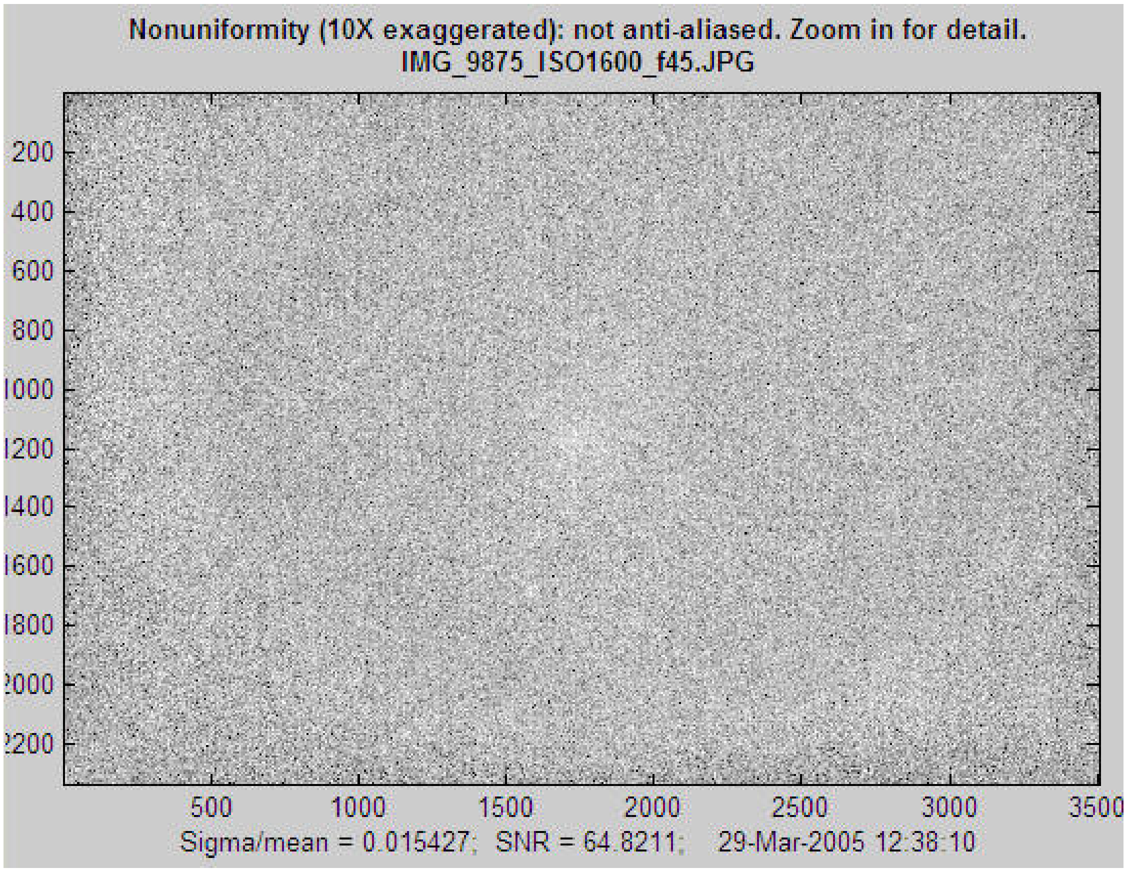
Exaggerated local noise (standard)	Exaggerated image of local noise
Local noise with added contours	Exaggerated image of local noise with added contours
Pseudocolor contours with colorbar	Pseudocolor image of local density variations. The image has been smoothed. Colors vary from image to image: the color map covers the density range of the image.
Spot detection w / threshold (pseudocolor)	Pseudocolor image emphasizing spots. Fixed color map. Image is normalized to the mean density. For clarity, only densities between 0.9 and 1 are displayed in the color map.
3D Pseudocolor Contours shaded	3D pseudocolor image may be rotated for enhanced visualization. Shading emphasizes contour shapes.
3D Pseudocolor Contours	The Colormap (which relates color to levels) is more accurate

	without shading.
3D Inverted Pseudocolor Contours shaded	Inverts the data (Z-axis)
3D Inverted Pseudocolor Contours	
3D Spot detection, pseudocolor shaded	3D spot detection. The Z-axis is always inverted so spots stand out.
3D Spot detection, pseudocolor	

The local noise figures are produced by

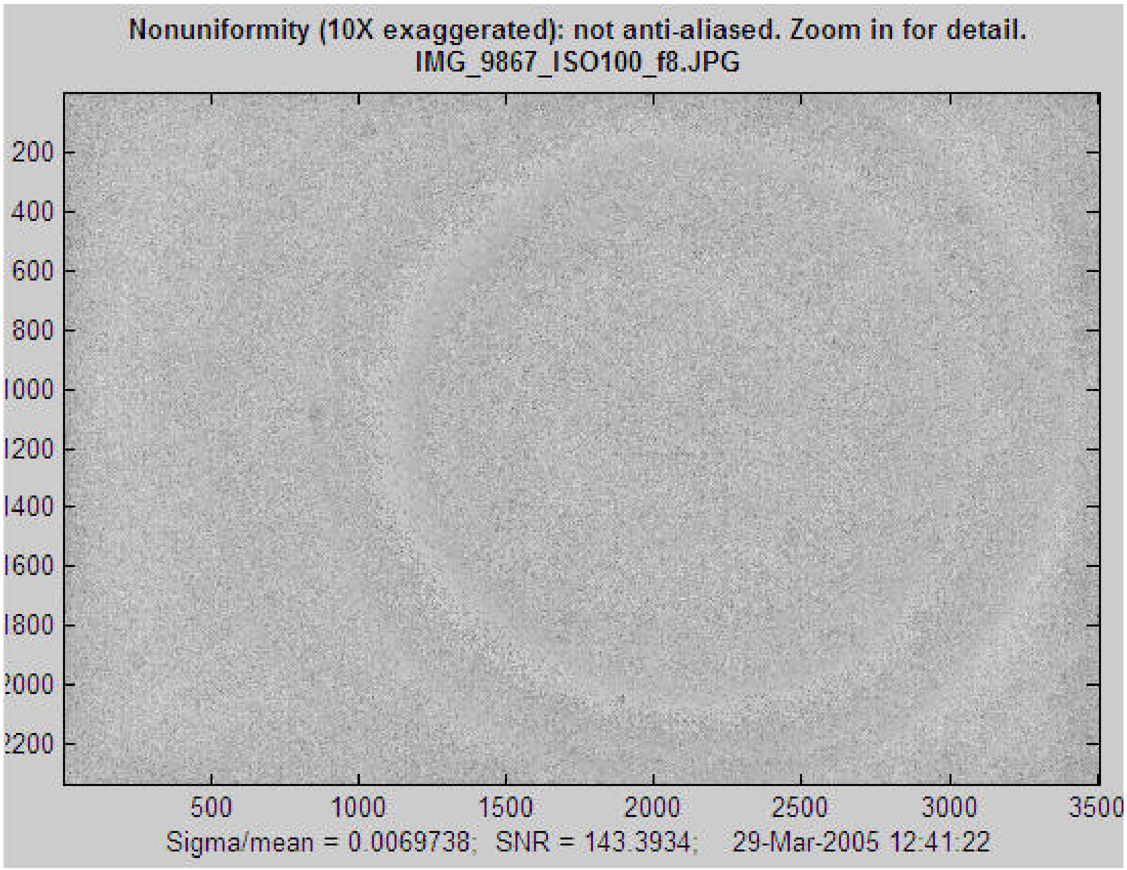
1. Subtracting a highly smoothed version of the image from the image itself. This removes broad image variations (low spatial frequencies), leaving only the fine detail. **(*The signal is highpass filtered.*)** Exaggerating the fine detail by a factor 5x or 10x, depending on the signal-to-noise ratio (the average pixel level of the original image divided by the standard deviation of the difference image (the results of step 1), i.e., the RMS noise). Adding an offset to the the exaggerated signal so the average level of the image is displayed as middle gray.
2. If **Local noise with added contours** is selected, contours are calculated by subtracting the same highly smoothed version of the image from a moderately smoothed version of the image. Smoothing is necessarily because noise would make the contours unintelligibly rough.

The first image (below) shows noise detail for the Canon EOS-20D at ISO 1600 with the 10-22mm lens set to f/4.5. No surprises here; electronic noise dominates.



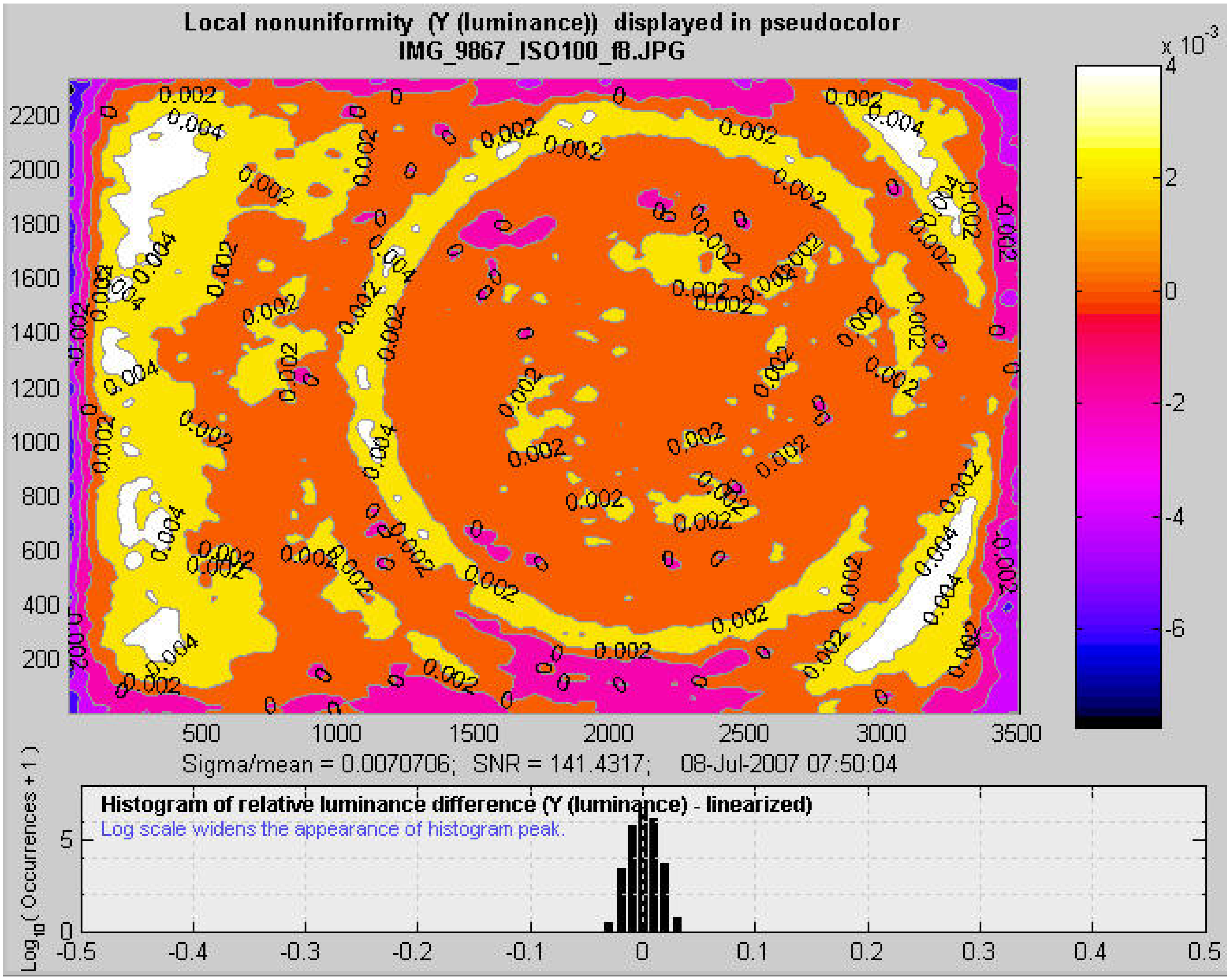
Noise detail for Canon EOS-20D, ISO 1600, 10-22mm lens, f/4.5.

The second image (below) shows noise detail for the Canon EOS-20D at ISO 100 with the 10-22mm lens set to f/8. Thanks to the small aperture, some very faint dust spots are visible. The dust is on the anti-aliasing/infrared filter/microlens assembly in front of the sensor. This assembly can be well over 1 millimeter thick. Stopping the lens down (increasing the f-stop setting) reduces the size of dust spots but makes them darker. This image has a surprise in the form of concentric circles: bands where the noise appears to be higher or lower than the remainder of the image. This may be caused by (a) the Analog-to-Digital (A-D) converter in the image sensor chip, which can have small discontinuities when, for example going from level 127 to 128: binary 01111111 to 10000000, or (b) JPEG artifacts. Rrecall that these noniniformities are exaggerated by a factor of 10: they would be invisible or barely visible on an actual image; you might seem then faintly in smooth areas like skies.



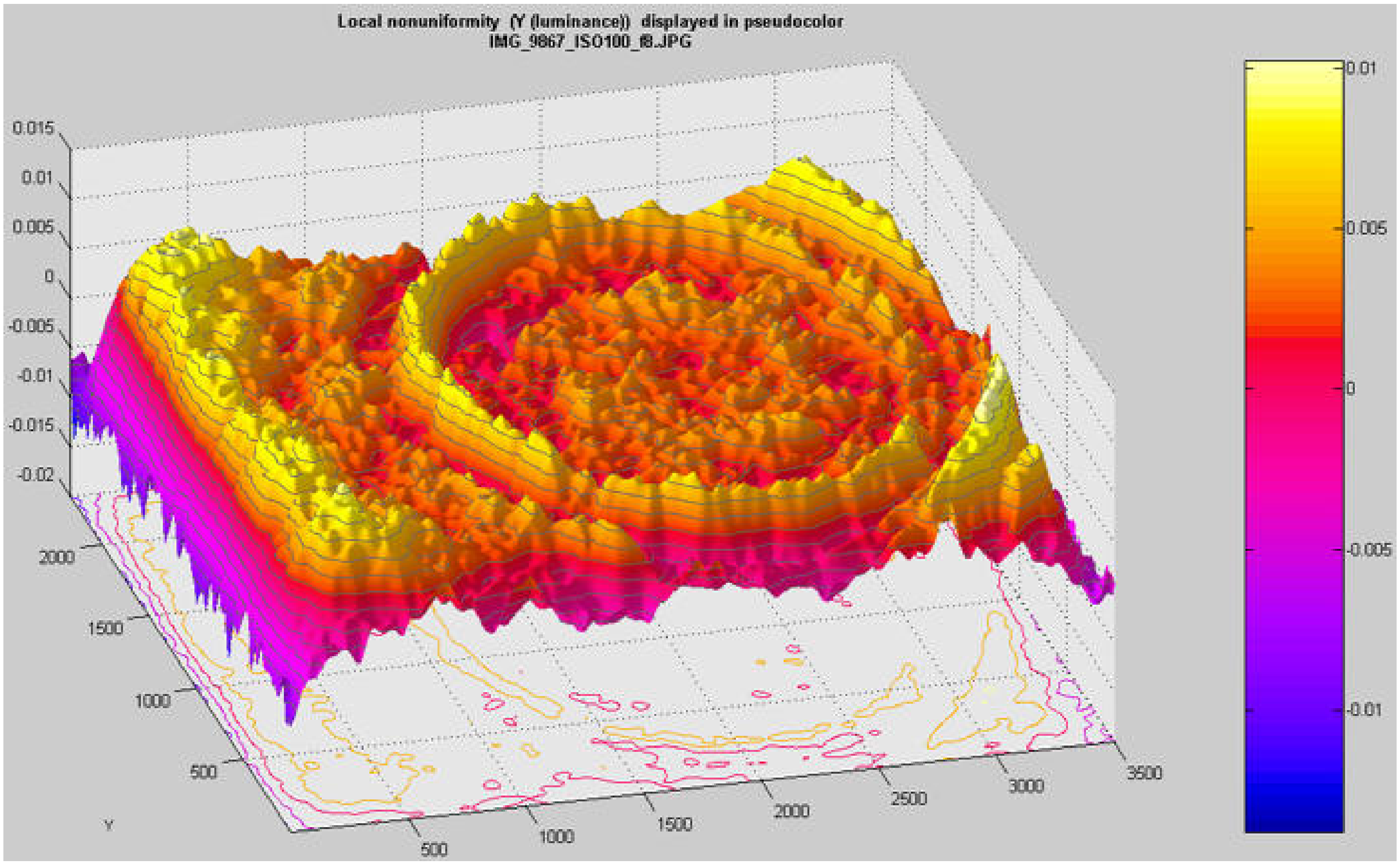
Noise detail, Canon EOS-20D, ISO 100, 10-22mm lens, f/8.

Here is the same image, displayed in pseudocolor (which shows the amount of variation) with a color bar, and including a histogram (of individual pixels, not the smoothed image used to generate the contour plot on the left). The scale varies from image to image; it is not fixed like the scales for for the luminance and f-stop contour plots (which display long range, low spatial frequency variations). The histogram is narrower than the separate histogram image (above) because long-range (low spatial frequency) density variations have been removed. It is a good approximation to the average sensor noise.



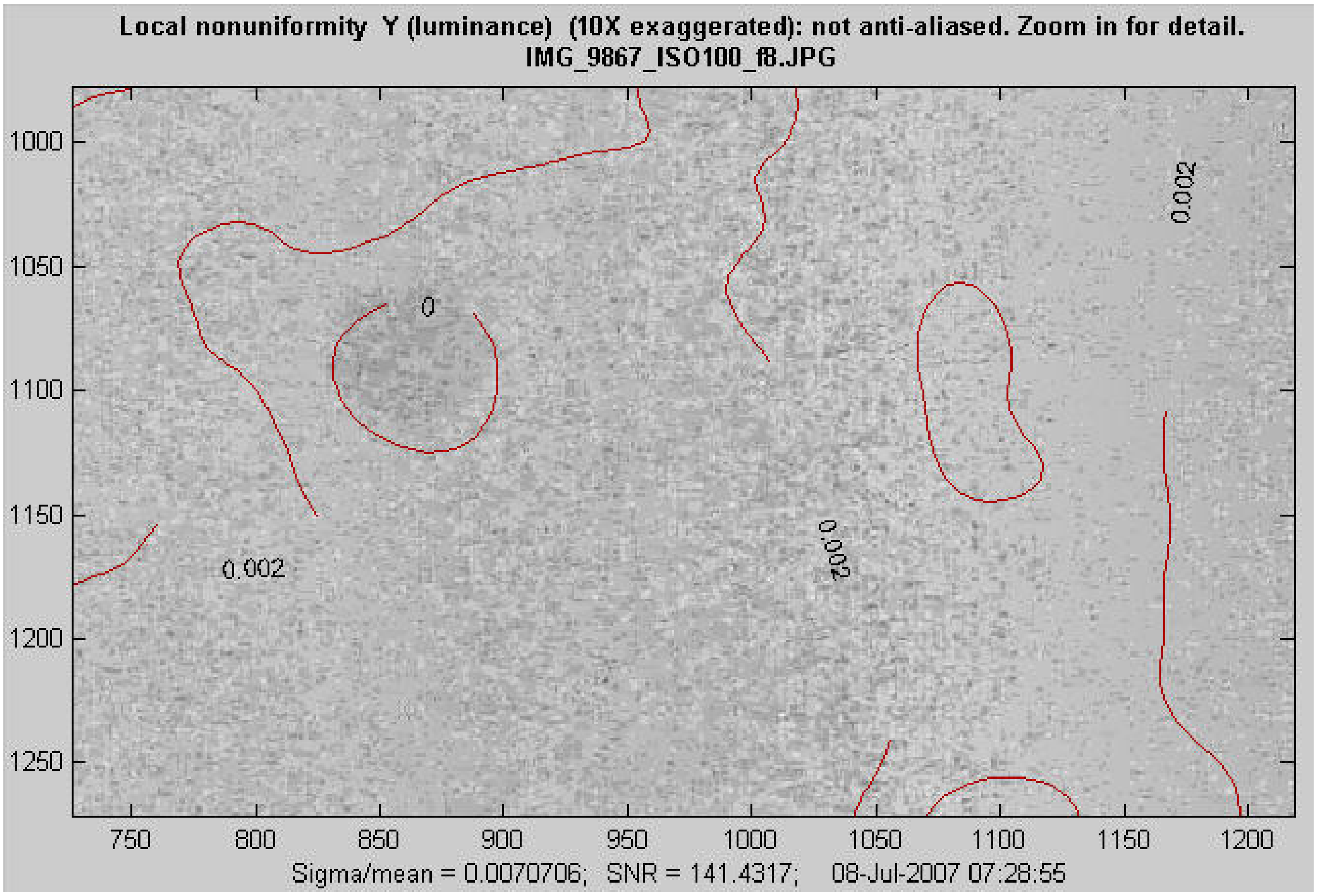
Local nonuniformities shown in pseudocolor, Canon EOS-20D, ISO 100, 10-22mm lens, f/8.

The same results displayed in 3D are quite impressive. This image can be rotated for enhanced visualization. The circular patterns may originate with reflections between the light source, lens, and sensor.



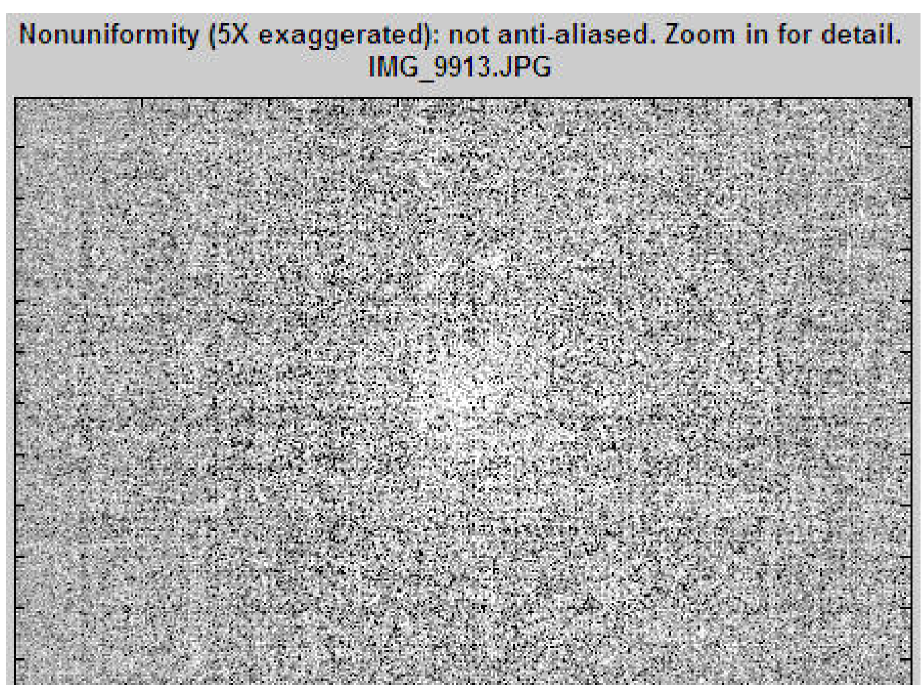
Local nonuniformities shown in 3D shaded pseudocolor,

The image below is an enlargement (a zoom) of the above image, centered on the dust spot to the left of the center. You can zoom into an image by using the mouse to draw an rectangle, or by simply clicking on a feature you want to enlarge. You can restore the original image by double-clicking anywhere on the image.



The following image is the noise detail from a 2 f-stop underexposed image with maximum luminance = 0.161 (out of 1), f/4.5, ISO 100. It shows a clear pattern. Although it looks alarming, this pattern is invisible because (a) it is in a very dark region, (b) it is ***aliased***. The actual pattern has a much higher spatial frequency, hence is less visible. You need to zoom in to view the true pattern, which is less visible than it appears here.

Noise detail, illustrating aliasing. (The actual noise is not as bad as it looks.)

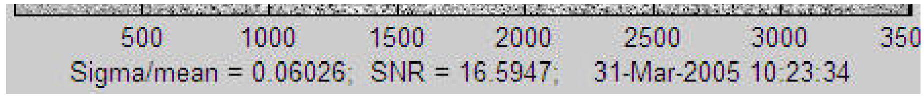


Spot detection (Imatest Master only)

> **Note:** Spot detection is handled with much more detail and sophistication in the Blemish Detect module, which allows the spot filtering and thresholds to be tuned to the human eye.

When **Spot detection w/**

threshold (pseudocolor) is selected in the Noise detail popup menu, the pseudocolor display emphasizes dark spots (the type that result from dust on the sensor) and minimizes noise, light spots, and long range density variations. The following webcam image (originally 1600 pixels wide) has two rows of five simulated spots (added by an image editor). Other irregularities are from the sensor itself..



Webcam image with 10 simulated spots (5 in each of 2 rows)

With the standard **Pseudocolor contours with colorbar** display, the darker spots are clearly visible, but the lighter spots are lost in the overall density variations.

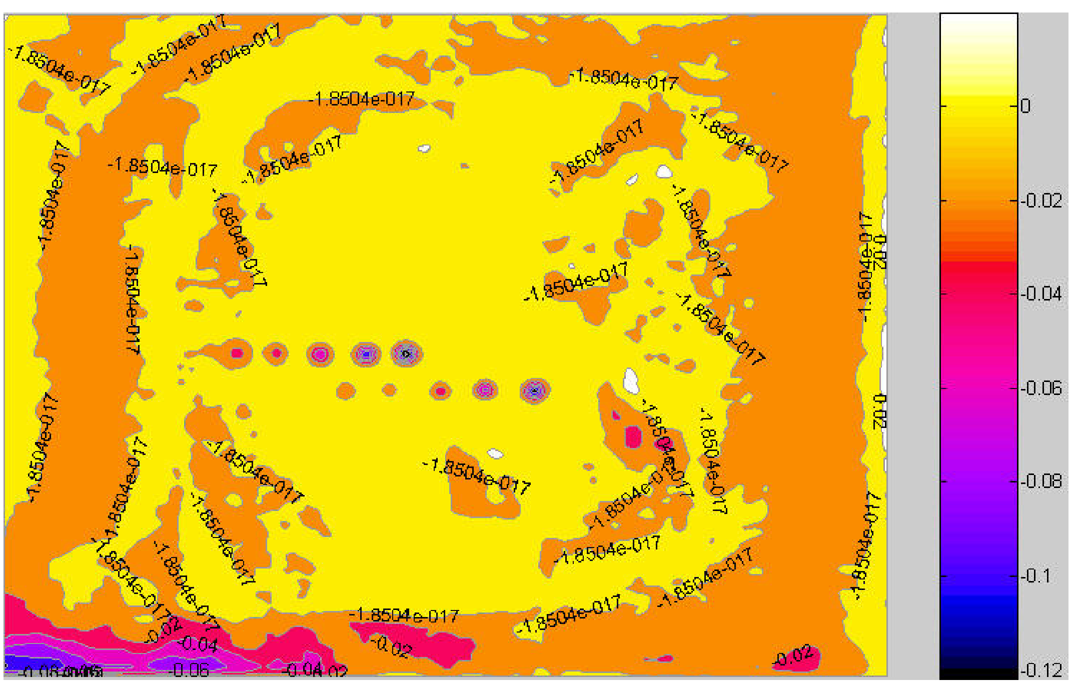


Image with spots: standard pseudocolor display

But they stand out in the Spot detection display. The differences in the algorithms are described below.

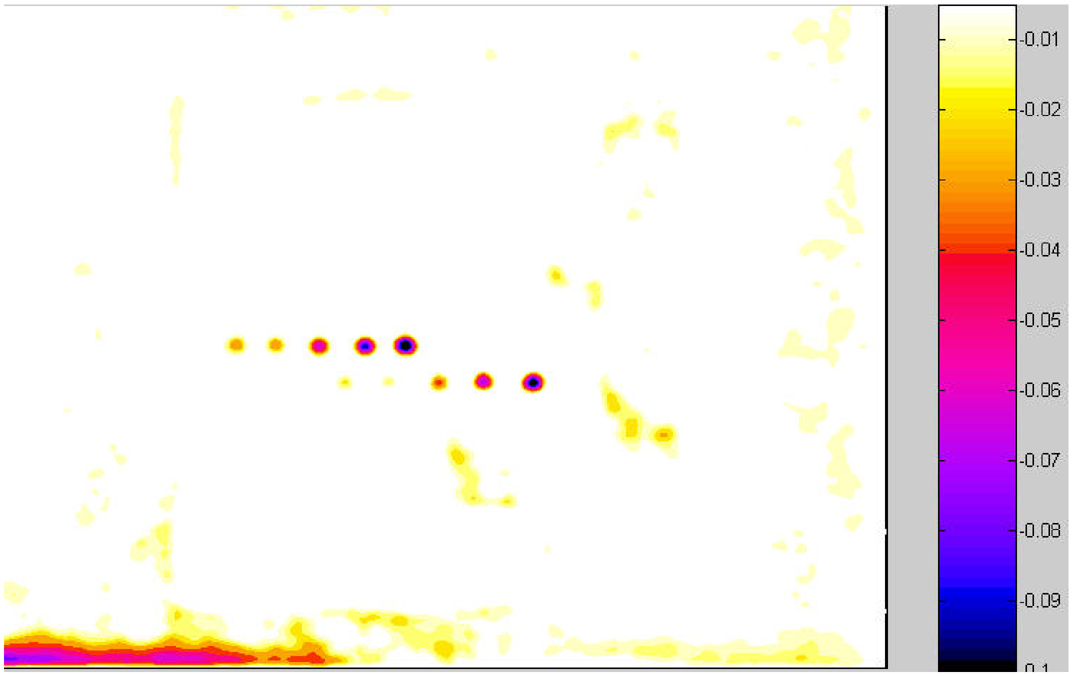


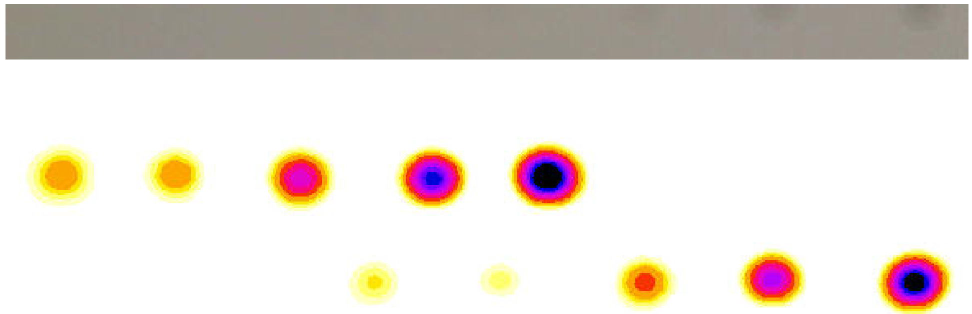
Image with spots: Spot detection display

When **Pseudocolor contours with colorbar** is selected, the image is normalized to its average level. Then the local variations are calculated by subtracting a highly smoothed version of the image from a moderately smoothed version of the image. This is the same data used for the contours in the **Local noise with added contours** display, described above. When **Spot detection w / threshold (pseudocolor)** is selected, there are several differences.

- The “highly” smoothed version of the image is less aggressively smoothed. This emphasizes local variations more strongly.
- The contour plot has a fixed color map, showing only values between = -0.005 (-0.5%), which is about the threshold of visibility for a spot, and -0.1 (-10%), which is the density for a highly visible spot. All values above -0.005 are displayed as white and all values below -0.1 are displayed as black. The color map for the standard pseudocolor plot is variable, based on the minimum and maximum values of the processed image.

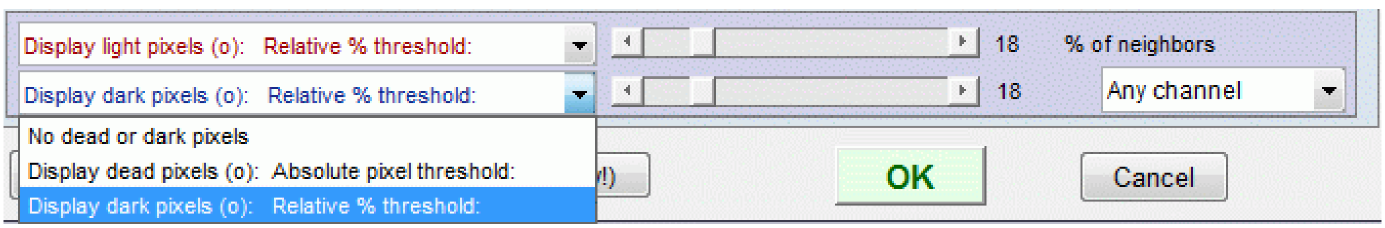
This approach removes much of the interfering detail from the final plot so that spots are clearly visible.

Detail: Simulated spots and Spot detection display



Fourth order fit: y = c(1)*r^4 + C(2)*r^3 + … + c(5) where r is normalized to center-to-corner.					
R	0.045	-0.108	-0.081	-0.083	0.866
G	-0.124	0.207	-0.295	-0.037	0.922
B	-0.189	0.315	-0.341	-0.037	0.907

Hot and dead pixels By checking the appropriate boxes you can display hot or light pixels (**red x**) and/or dead or dark pixels (**blue •**).



The definition depends on whether **Absolute pixel threshold** or **Relative % threshold** is selected: