Imatest - Using Uniformity

Measure lens vignetting and sensor nonuniformity

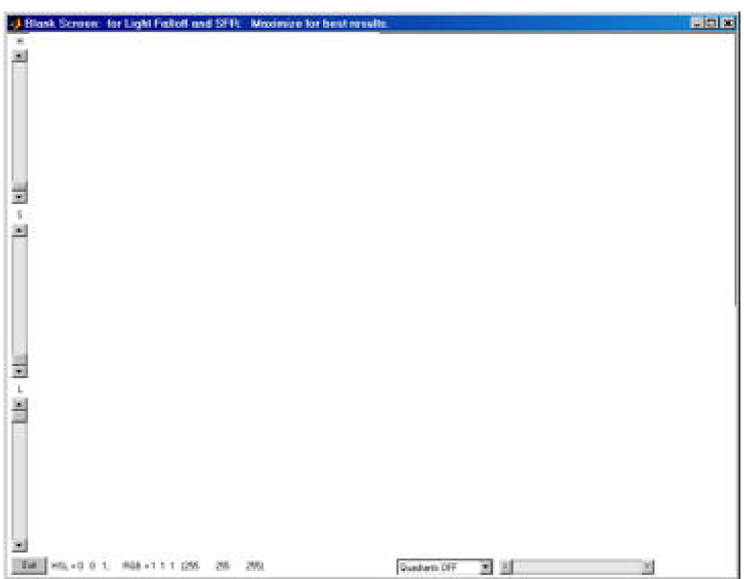
Uniformity (formerly ***Light Falloff***) measures lens vignetting (dropoff in illumination at the edges of the image) and other image, illumination, and sensor nonuniformities. For example it can measure evenness of flash illumination (using light bounced off a white wall) or the uniformity of flatbed scanners. In Imatest Master, Uniformity can also display a pixel level histogram, analyses of hot and dead pixels and color shading, and a detailed image of fine nonuniformities (i.e., sensor noise). These features are described in Uniformity instructions: Imatest Master .

New in Imatest 3.7
A minor error has been fixed for the case when the sizes of the corner and side regions were set between 1% and 10% and the image was over 600 pixels wide. The sizes were smaller than indicated.

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.

Instructions

To prepare an image for Uniformity,

- Set your camera or lens to ***manual focus*** and focus it at ***infinity*** (the worst case for light falloff).
- 

Screen Pattern module for Uniformity.

Photograph an evenly illuminated uniform subject.

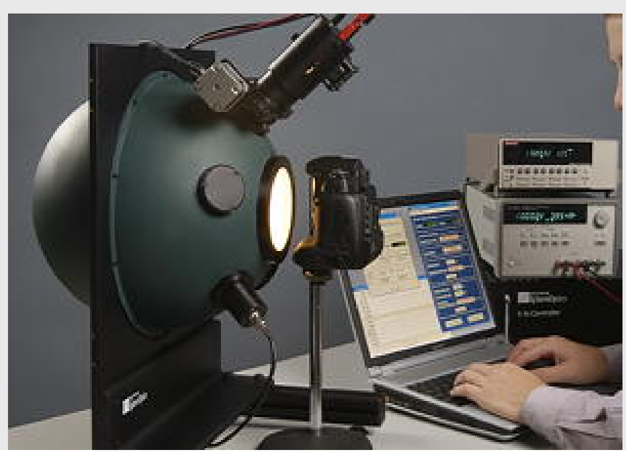
- One of the simplest ways to obtain a uniform subject is to photograph your computer monitor at a distance of 1-3 inches (2-8 cm) using the Imatest Screen Patterns module, shown on the right. Click on on the right of the Imatestmain window, then maximize the screen. You can adjust the Hue, Saturation, and Lightness (H, S, and L, which default to 0,0,1) if required.

This method works best with flat screen LCDs with wide viewing angles (not so well with laptops).

- An additional diffuser is strongly recommended, especially for extreme wide angle lenses or laptop screens with a limited viewing angle. We recommend using opal diffusing glass mounted close to the lens. Opal glass is available in the US from Edmund Optics. (Thanks to Bart van der Wolf for the suggestion.) If a diffuser is used, a light box may be substituted for the monitor. (Light boxes are typically brighter but less uniform.)
- CRTs are not recommended because their raster scan tends to make exposures less uniform.
- *(We prefer the LCD monitor, but this approach may work in come cases.)* Photograph an evenly-lit smooth matte sheet (white or gray). Be careful not to shade it. Outdoors illumination (shade) sometimes provides very even illumination. Getting uniform illumination can be a challenge with ultrawide lenses; it's almost impossible to avoid shading part of the card. Opal diffusing glass is strongly recommended.
- The subject does not need to be in focus (you don't even need a lens to measure sensor uniformity); the goal is to measure lens light falloff and/or sensor uniformity, ***not*** features of the subject. For typical measurements, set exposure compensation to overexpose by about one f-stop. (You may, however, use any exposure you choose.)
- Save the image as a RAW file or maximum quality JPEG.

To obtain truly even illumination

for precision scientific measurements you'll need an ***integrating sphere*** from a supplier such as Image Engineering, SphereOptics, Labsphere, or Electro-Optical Industries (EOI).
The SphereOptics system on the right is about $8,000, including variable attenuator, power supplies, operating software, and calibration. It is available in sizes from 4 to 76 inches.



The Image Engineering Spherical Transparency Illuminator LE6 was designed for a variety of

photographic applications. A mechanical shutter
can dim the light down to 1% of the maximum illumination without changing the color temperature.

The DSC Labs Ambi Illuminator also provides extremely even illumination from a variety of external light sources. It is excellent for illuminating transparencies.

Integrating spheres aren't cheap. Controlling Veiling Glare in an Optical Imaging System by Amber Czajkowski (University of Arizona) contains a description of a really neat do-it-yourself integrating sphere project, based on stainless steel balls from http://www.gazingballoutlet.com, which sells balls up to 30 inches (0.75 meters) in diameter! A 16 inch (40 cm) ball is under $100 USD.

Other less expensive alternatives include Kyoritsu calibrated light sources (especially the pattern light boxes), available in the North America from C.R.I.S. Tsubosaka (Japan) also has some interesting products. There are no obvious US or European distributors. Also of interest: DNP Light boxes.

To run Uniformity,

- **Start** Imatest and click on . **Very large files** (height x width x colors over 40 MB) may cause memory overflow problems. Files over 40 or 80 MB can be automatically reduced 1/2x linearly (using 1/4 the memory). Click **Settings**, **Options I** (in the Imatest main window) and make the appropriate setting in **LARGE FILES (Uniformity, Distortion)**. Open the image file.

Multiple file selection Several files can be selected in Imatest Master using standard Windows techniques (shift-click or control-click). Depending on your response to the multi-image dialog box you can combine (average) several files or run them sequentially (**batch mode).**

Combined (averaged) files are useful for measuring fixed-pattern noise (at least 8 identical images captured at low ISO speed are recommended). The combined file can be saved. Its name will be the same as the first selected file with _comb_*n* appended, where *n* is the number of files combined.

Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

If the order of the files in a batch runs is different from the selection order, click Settings, Options I (in the Imatest main window) and change the setting in **Batch**

run order. The sequence may be affected by Windows Explorer settings.

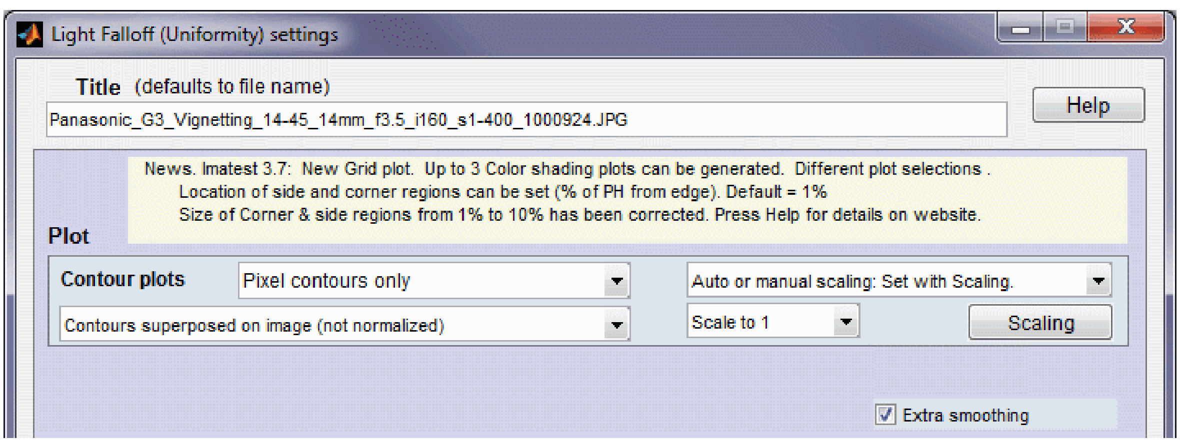
One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the **Close figures after save** checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

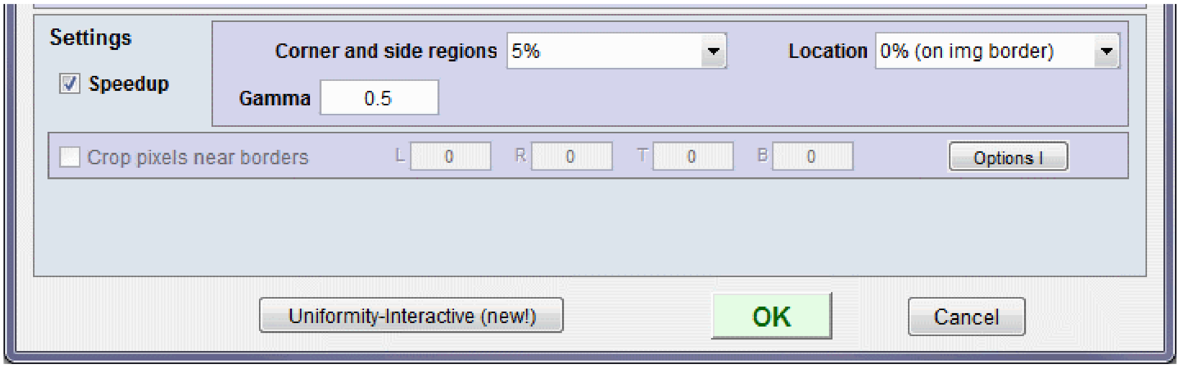
Three cropping (ROI selection) options are available by clicking in the Imatest main window. These include

Don't ask to crop. (Use Crop … borders 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.

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, is typically preferred.

A dialog box appears. The following settings appear in all Imatest versions. More selections are available in Imatest Master.





Input dialog box in Imatest Studio

- **Title** Defaults to the file name. You can change it if you wish.
- **Display Uniformity contour plots** (**Plot** area; on by default). Often set to **Display pixel and f-stop contours** (two plots), but may be turned off or set to display only. Available settings are

No contour plots
Display pixel and f-stop contours
Display pixel contours only
Display f-stop contours only

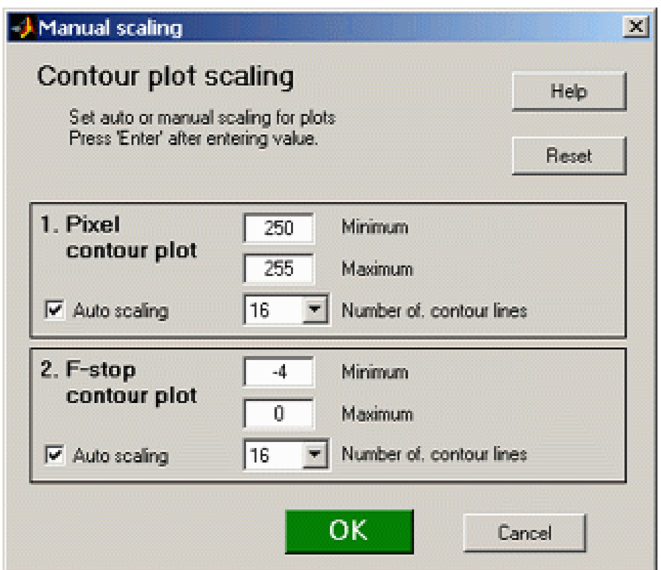
- **Contour plot display options** Eight display options are available. 3D plots are not generally recommended because they can be slow. Normalized refers to the first (level) plot only (not to the displayed numeric results).

Contours superposed on image (not normalized)
Contours superposed on image (normalized to 1)
Pseudocolor with colorbar (not normalized)
Pseudocolor with colorbar (normalized to 1)
3D pseudocolor w/colorbar (not normalized)
3D pseudocolor w/colorbar (normalized to 1)

3D pseudocolor shaded w/colorbar (not normalized)
3D pseudocolor shaded w/colorbar (normalized to 1)

- **Scaling options**

Auto or manual scaling: Set with Scaling.	Scaling set by button.
Scaling: 0 – 1 or 255: -4 – 0 f-stops	Fixed scaling: 0 – 1 or 255 for Luminance pixel plot; -4 – 0 f-stops for f-stop plot.
Scaling (min – max)	Fully automatic scaling.

- 

Manual scaling for contour plots

Contour plot scaling Scale to 1 or Scale to 255

sets the scaling for the pixel level (the first) contour plot.

- : Opens a dialog box that lets you select manual or automatic scaling for the two contour plots. **Minimum** and **Maximum** set the scale when **Auto scaling** is unchecked.
- **Extra smoothing** applies extra smoothing to the contour plots, making them less susceptible to variations from noise (and faster to plot). ***Strongly recommended***. Uncheck this box only for compatibility with older results.
- **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.

- **Corner and side regions** (default 32x32 pixels) allows you to select the areas at the corners and sides of the images to be analyzed. These affect the numeric readouts below the plots (example: Corners: worst = …). Choices include 10x10 pixels, 32x32 pixels, 1% (min. 10x10), 2% (min. 10x10), 5%, and 10%.

- **Location** Location of corner and side regions in units of image height (0, 1%, 2%, 5%, 10%, 15%, 20%). 0% was always implied prior to Imatest 3.8 (corner and side regions always abutted the image boundaries).

- **Gamma** (**Settings** area). The default value of gamma, 0.5, is typical for digital cameras. Gamma affects 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.

- **Crop pixels near borders (L, R, T, B)** (**Settings** area). Available only if **Don't ask to crop. (Use Crop … borders settings in LF input dialog box.)** is selected in the in the Imatest main window. If checked, the image is cropped by the number of pixels indicated near the left, right, top, and bottom borders.

- **Crop pixels near borders (L, R, T, B)** (This feature is normally disabled.) Enabled only if **Don't ask to crop. (Use Crop … borders settings in LF input dialog box.)** is selected in the Options I. If checked, the image is cropped by the number of pixels indicated near the left, right, top, and bottom borders.

Two methods of region selection

The region to be analyzed (ROI) is normally set in the coarse and fine region adjust windows, where the ROI is defined relative to the upper-left corner, *not* to each of the edges. So if you want a constant margin for several images (for example, you want the ROI boundaries to be 4 pixels from the borders), ROI must be set individually for each image size.

Blemish Detect offers an alternative method of specifying the ROI relative to the image boundaries: crop_borders, which is set with **Crop pixels near borders** near the bottom of the Uniformity (or Blemish) window when **(Use Crop … borders settings in LF input dialog box.)** is selected in and the **Crop pixels…** box is checked. Otherwise, crop_borders is ignored and the standard ROI selection is used.

The following options are available in Imatest Master only. They are discussed in detail in Uniformity instructions: Imatest Master.

- **Channel** (**Settings** area) You can choose between Red, Blue, Green, and Y (luminance) channel
- **Hot and dead pixels** (**Settings** area) By checking the appropriate boxes you can display hot pixels (**red x**) and/or dead pixels (**blue •**). Hot pixels are stuck at or near the sensor's maximum value (255 in 8-bit files) and dead pixels are stuck at or near 0. You can choose between hot/dead pixel detection in any channel, all channels or the selected channel.

> *Because signal processing— especially JPEG compression— can cause 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. Settings are saved between runs. JPEG files must be saved at the highest quality level for this feature to work; isolated hot and dead pixels tend to be smudged at lower quality levels. Details are described in Uniformity: Imatest Master.*

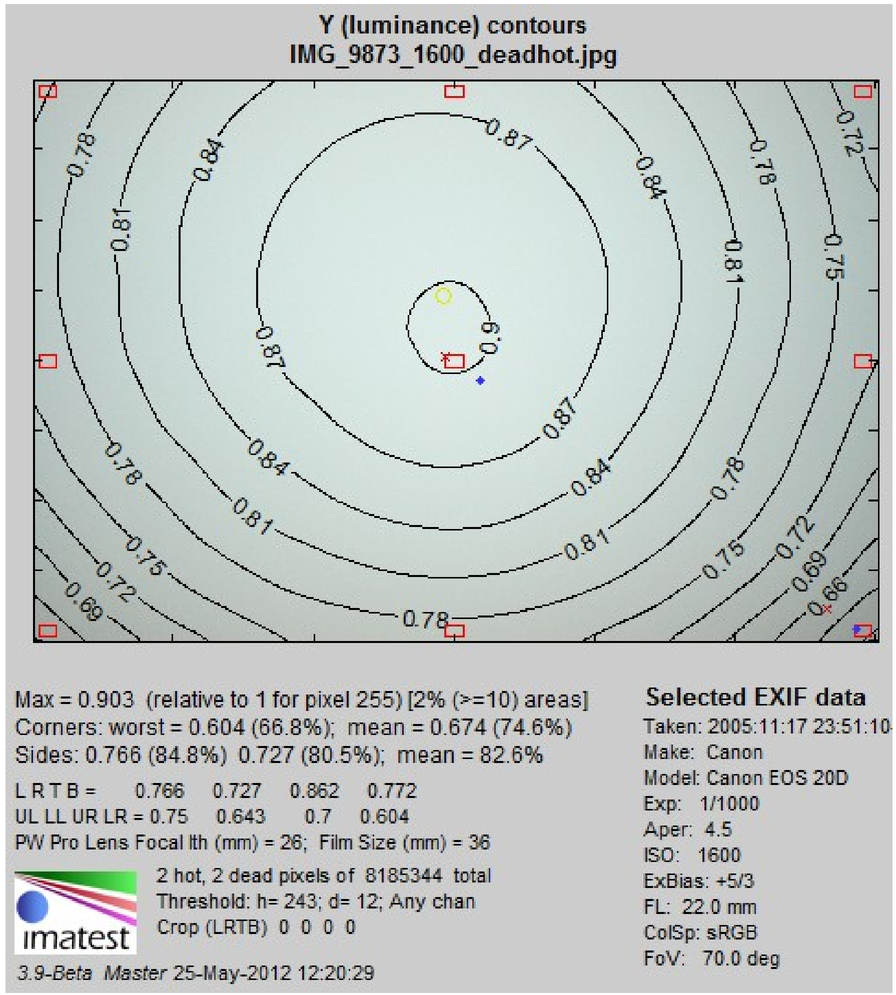
- **(Plot area) Color shading** displays color nonuniformity. Several options are available. **Display Histogram** displays histograms of R, G, and B channels. **Display color uniformity profiles** displays R, G, and B values (or ratios— several options available) along the diagonals and horizontal and vertical center lines. **Display fine detail** displays a detailed figure of noise and sensor uniformity with an option for spot detection.. The calculation can be slow and uses ***lot***s of memory. Details in Uniformity: Imatest Master.

Results

The first figure: luminance contour plot

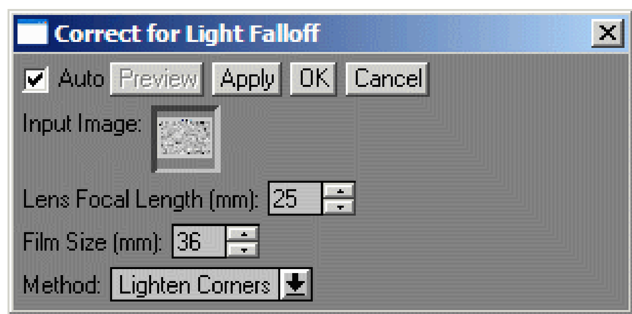
shows normalized pixel level contours for the image file luminance channel, where luminance is defined as Y = 0.30*R + 0.59*G + 0.11*B.. A maximum value of 1 corresponds to pixel level = 255 for image files with a bit depth of 8 or 65535 for a bit depth of 16. Some illumination nonuniformity is evident in the plot: the top is brighter than the bottom. The image is smoothed (lowpass filtered) before the contours are plotted. The side and corner regions are shown as red rectangles. The approximate location of the maximum luminance is indicated by a yellow **O**.

Luminance (relative pixel level) contour plot



The text displays the maximum unnormalized pixel level for the luminance channel, the worst and mean corner values (in unnormalized pixel levels and as a percentage of maximum), and the side values. Selected EXIF data is shown on the right. Two hot and two dead pixels (which were simulated) were detected with thresholds of 243 and 12 (pixels), respectively. The crop (Left, Right, Top, Bottom) is shown just below. Details below.

The setting for correcting light falloff in the Picture Window Pro Light falloff transformation is also given. The PW pro Light Falloff dialog box is shown on the right. Film Size (mm) remains at 36 (the PW Pro default value: the width of a 35mm frame). Picture Window Pro is the powerful and affordable photographic image editor that I use for my own work. The Lens Focal Length is rarely the exact focal length of the lens.



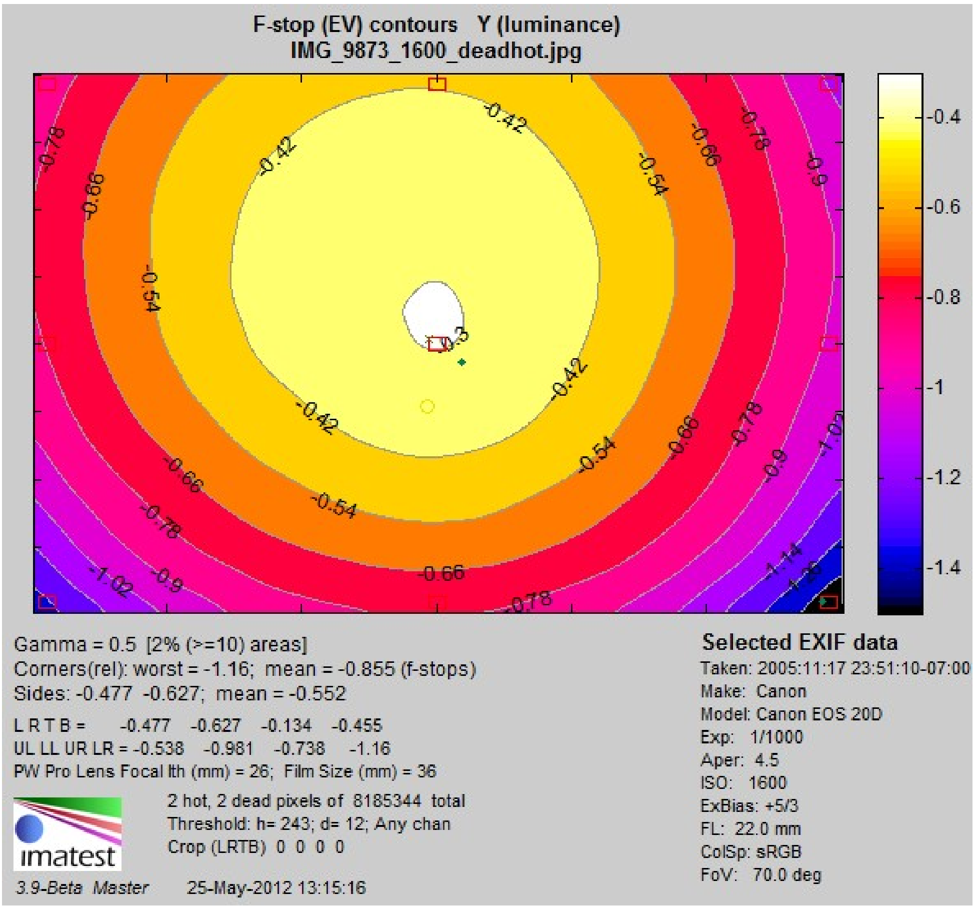
Light falloff depends on the lens aperture (f-stop) as well as a number of lens design parameters. Lenses designed designed for digital cameras, where the rays emerging from the rear of the lens remain nearly normal (perpendicular) to the sensor surface, tend to have reduced light falloff. For aesthetic purposes I generally recommend ***undercorrecting*** the image, i.e., using a larger Lens Focal Length. This makes the edges somewhat darker, which is usually pleasing. Ansel Adams routinely burned (darkened) the edges of his prints. Part of the reason was that he had to compensate for light falloff from his enlarger (when he wasn't contact printing).

> *"My experience indicates that practically every print requires some burning of the*

> *edges, especially prints that are to be mounted on a white card, as the flare from the card tends to weaken visually the tonality of the adjacent areas. Edge burning must never be overdone…"   —Ansel Adams, "The Print," p. 66. 1966 edition.*

The second figure: f-stop contour plot

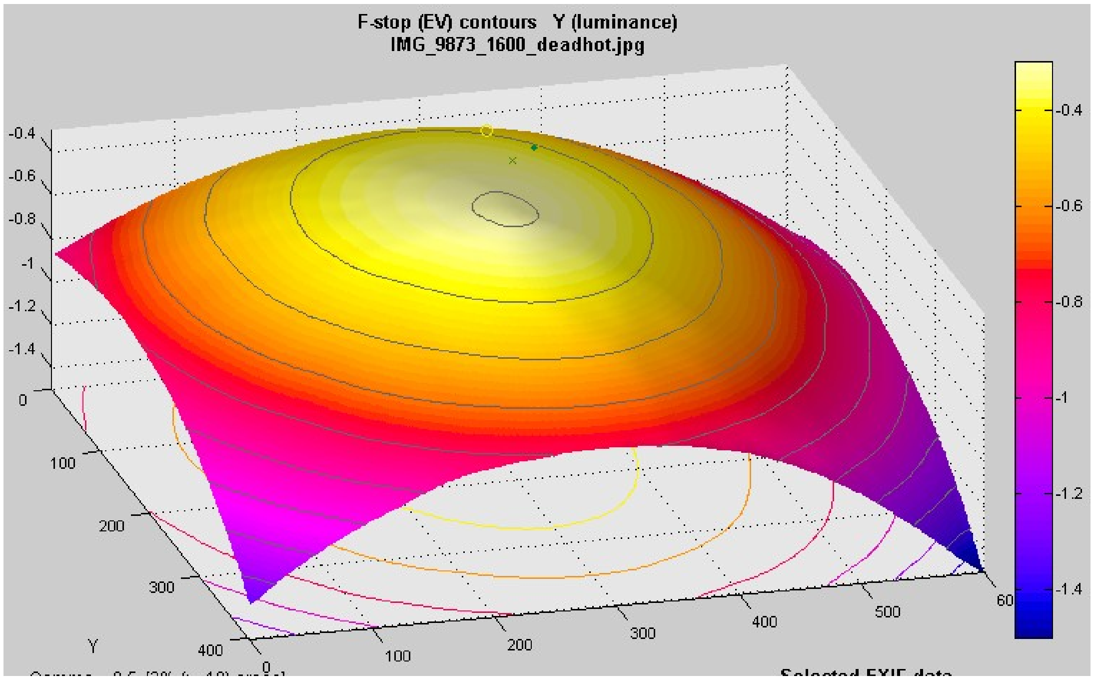
shows image file luminance contours, measured in f-stops, normalized to a maximum value of 0. A pseudocolor display with color bar has been selected. The colors in the color bar are fixed: colors always vary from white at 0 f-stops to black at -4 f-stops and darker. For this plot to be accurate, a correct estimate of gamma (the camera's intrinsic contrast) is required. Gamma is measured by Stepchart, using any one of several widely-available step charts, or by Colorcheck.



F-stop contour plot in pseudocolor (normalized)

Gamma can be tricky to measure for several reasons. (1) Many cameras have complex response curves, for example, "S"-curves superposed atop gamma curves. This means that gamma can vary with brightness. (2) Some cameras employ adaptive signal processing in their RAW conversion algorithms. This increases contrast (i.e., gamma) for low contrast subjects and decreases it for contrasty subjects. This improves pictorial image quality for a wide range of scenes, but makes measurements difficult, especially since Uniformity targets have the near-zero contrast.

Both contour plots are available as 3D plots (Master-only). The following 3D plot is unnormalized and shaded. 3D plots are rarely used because they are slow (but they can be pretty).



3D shaded pseudocolor F-stop contour plot (unnormalized)

Deriving f-stop falloff

The f-stop falloff in the second plot is derived from the equations,

Pixel level = k_1 luminance$^{\gamma}$;   Luminance = k_2 pixel level$^{1/\gamma}$ and

F-stop loss = $\log_2$(luminance ratio) = 3.322 $\log_{10}$(luminance ratio)

where luminance ratio is the ratio of the maximum luminance to the luminance in the area of interest, for example, the mean value of the corners.

Example: The first and second figures, above, are derived from the same image file. In the first figure, the mean pixel level at the corners relative to the center is 0.666/0.905 = 0.736 (73.6%). Since γ is assumed to be 0.5 (fairly typical of encoding gamma of digital cameras, the exposure at the corners relative to the center is $0.736^{1/\gamma}$ = 0.736^2 = 0.5416. The corresponding f-stop loss = $\log_2(0.5416)$ = 3.322 $\log_{10}(0.5416)$ = -0.885 f-stops. There is a slight discrepancy with the second figure, which calculates the mean at the corners (0.894 f-stops) *after* taking the logarithm to convert results into f-stops.

Additional figures are illustrated in Uniformity: Imatest Master .

.CSV and XML output files

The .CSV output file contains additional statistics. Most have obvious meanings.

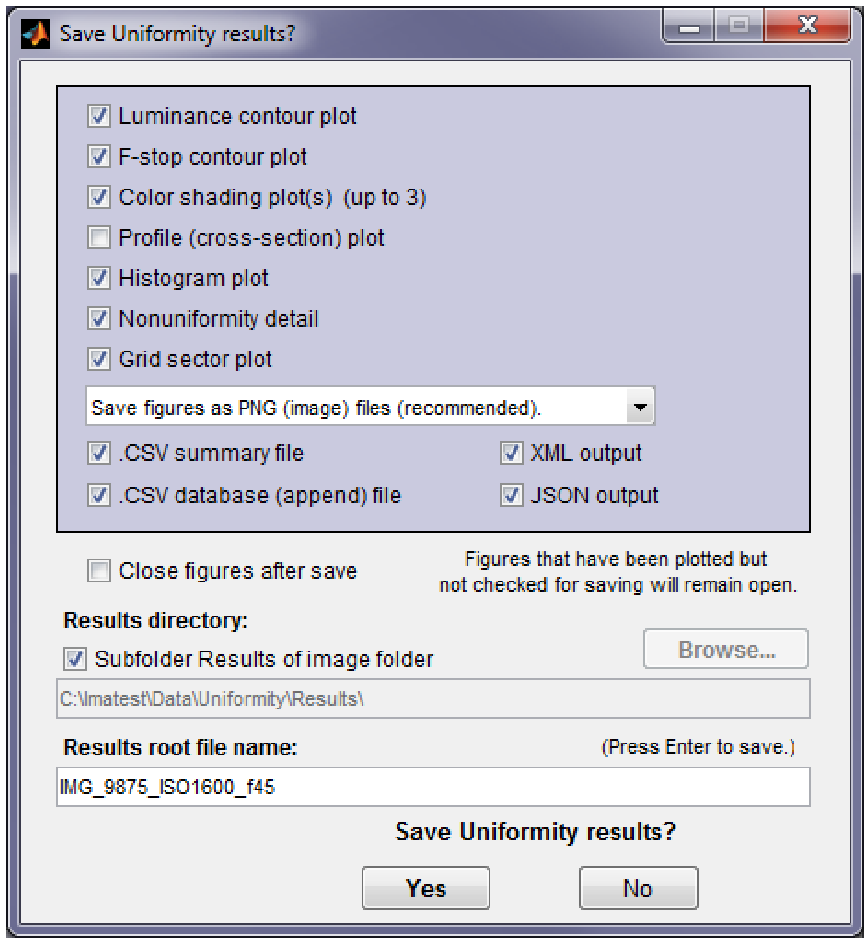
- Image pixels contains the width, height, and total size in pixels. Hot and Dead pixels show the total count and the fraction (divided to total pixels)

- The x and y coordinates of the hot and dead pixels are listed. The maximum is 100. Coordinates are in pixels from the top-left.

Contact *Imatest* if you need additional .CSV output.The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. Contact us if you have questions or suggestions.

Saving results

At the end of the run, a dialog box for saving results appears. It allows you to select figures to save and choose where to save them. The default is subdirectory Results in the data file directory. You can change to another existing directory by unchecking the **Save Results...** check box. The selections are saved between runs.



You can examine the output figures before you check or uncheck the boxes. Figures, CSV, XML, and JSON results are saved in files whose names consist of a root file name with a suffix for plot type and channel (R, G, B, or Y) and extension.

Example: IMG_9875_ISO1600_RGB_f-stop_ctrG.png. The root file name defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter. For batch runs, checking **Close figures after save** is recommended for preventing a buildup of figures (which slows down most systems). After you click on or , the Imatest main window reappears.

Figures can be saved as either PNG files (a standard losslessly-compressed image file format) or as Matlab FIG files, which can be opened by the button in the Imatest main window. Fig files can be manipulated (zoomed and rotated), but they tend to require much more storage than PNG files, and are therefore not recommended.

The CSV and XML files contain **EXIF data**, which is image file metadata that contains important camera, lens, and exposure settings. By default, Imatest uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting Phil Harvey's ExifTool, as described here.

Links

Vignetting by Paul van Walree, who has excellent descriptions of several of the lens (Seidel) aberrations and other causes of optical degradation.