

Digital Camera Imaging Evaluation



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Abstract

Most image processing and analysis is now done exclusively in the digital realm, effectively dictating the phasing out of film based cameras in favor of new high performance digital imaging systems.

Digital camera imaging must be evaluated objectively. Manufacturer specifications alone are not sufficient to properly ascertain actual camera performance. Objective testing is achieved using a standard test setup including a calibrated integrating sphere, certified targets, and a precision optical relay system. Uniform stable target illumination is provided by the integrating sphere. The target image plane is relayed onto the camera sensor array and captured for processing. A complete test set includes assessment of spatial resolution, sensitivity, uniformity, signal to noise ratio, modulation transfer function, and intrascene dynamic range.

A standardized digital camera imaging evaluation will be imperative when comparing systems of similar specification. Testing results will also serve to prove the validity of data acquired from camera systems on hand.

Introduction

Digital Imaging Evaluation

With imaging moving more and more exclusively into the digital realm the question of how to specify and maintain digital systems will be raised. Is it enough to merely take camera manufacturer resolution and sensitivity specifications at face value. What exactly degrades in a system subjected to unstable or hostile conditions. As with all types of hardware, digital imagers need to be subjected to standard tests to ascertain actual performance. A comprehensive test set that can be easily replicated and is exemplary for all pertinent camera characteristics will be required.

Test Set

Setup

Our test setup consists of an EOI Visible Image Projector (VIP) and a laptop PC. The VIP is a twelve inch (304.8 mm) integrating sphere with a two inch (50.8 mm) output port which feeds a filter/target dark-box and a set of relay optics. See Figure 1. The laptop PC has a frame grabber interface and is loaded with the EO TestLab Suite software package. See Figure 2. The unit under test (UUT) mounts to the relay optics using a standard F-Mount.

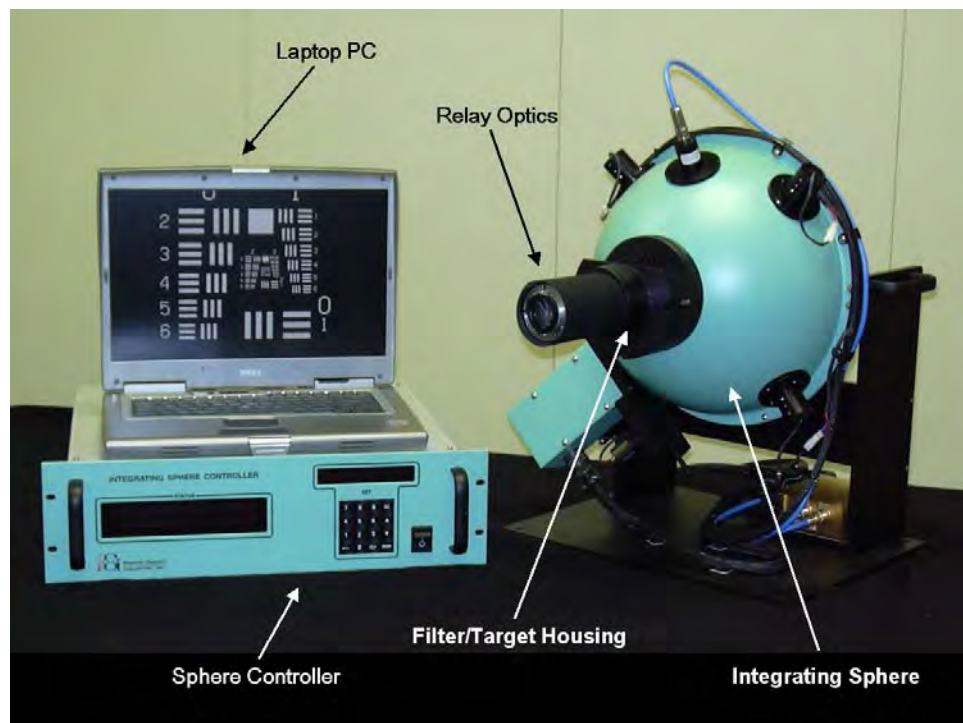


Figure 1. EOI Visible Image Projector Test Set Up

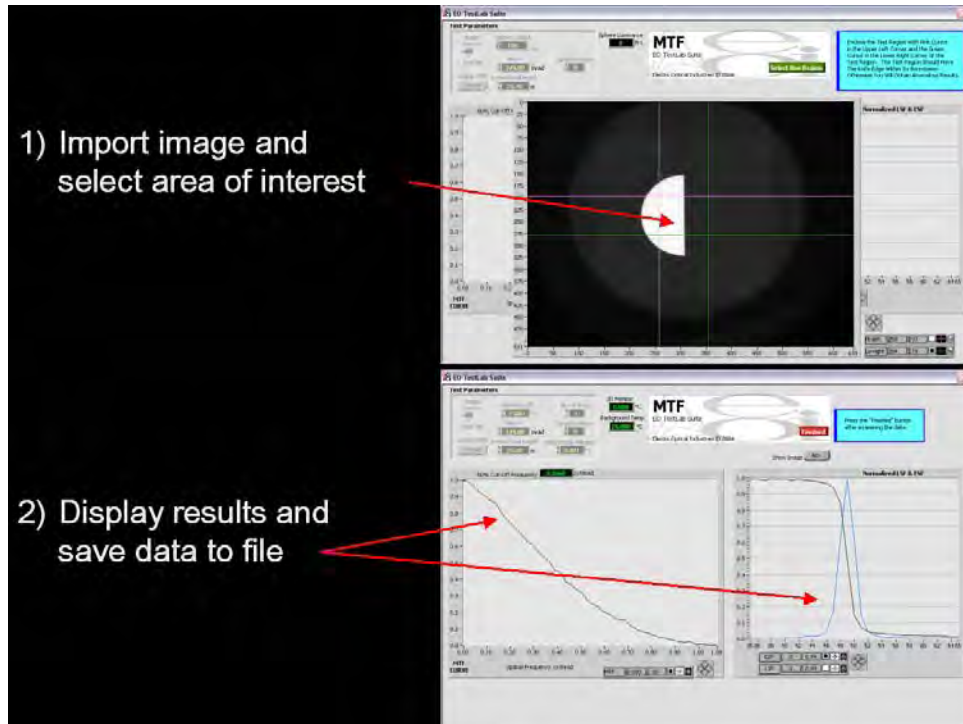


Figure 2. EO TestLab Example Screen Shots

Luminance is controlled either directly through the front panel of the VIP rack-mount controller or remotely via IEEE-488.2 from EO TestLab Suite. The range of the VIP is approximately 5 ft-L (1.5 cd/m^2) to 20,000 ft-L (5838 cd/m^2). Optional neutral density filters can be installed for extended low light testing.

EO TestLab can be used to control the VIP and capture test images grabbed from a standard video signal or it can import existing BMP or JPEG photographs for analysis. Typically for high resolution cameras a scaled video signal is available for monitoring, yet capturing frames from this source would yield limited resolution images unsuitable for camera characterization. Instead EO TestLab uses this video to first optimize system focus by displaying the real-time modulation transfer function, edge spread function, and line spread function of a selected target edge. Full resolution test images can then be captured to internal camera memory and later transferred to the laptop for processing.

Spatial Resolution

Spatial Resolution is a subjective test used to measure apparent resolvable resolution in cycles, or lines, per millimeter. This test is not computationally intensive and is instead based on the interrogation of an image by a trained observer.

Testing is performed using the traditional 1951 USAF Target. Both a positive and negative rendition of the chrome on glass target is utilized to gather data. See Figure 3. Test images are captured with luminance set to approximately 90% of UUT saturation.

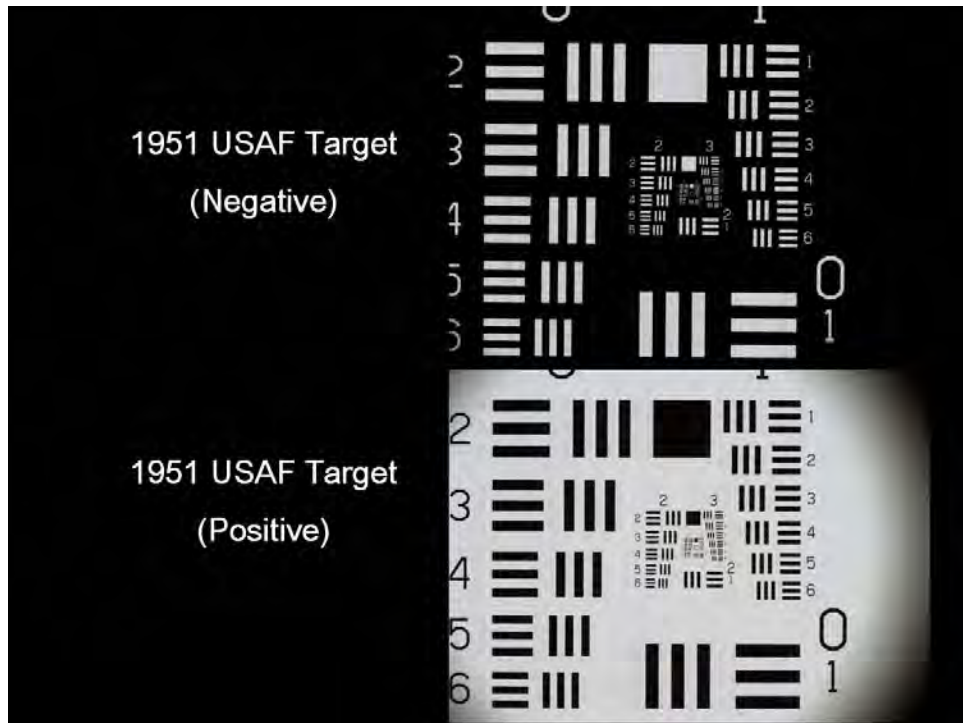


Figure 3. Spatial Resolution Test Images

The observer reviews the images by enlarging the area of interest using a non-blurring pixel zoom and determines the smallest resolvable three-bar pattern. By definition of the 1951 USAF pattern, resolution is stated in cycles/mm based on the resolvable group and element. Average horizontal and vertical resolution is reported based on both the positive and negative targets.

Uniformity

The Uniformity test characterizes inconsistencies across the sensor array by exposing it to a uniform scene. It is measured by capturing an image with the filter/target dark-box wide open to the integrating sphere set to approximately 50% of UUT saturation luminance. See Figure 4. The center 20% square area of the captured image is interrogated by EO TestLab to determine the standard deviation, mean, minimum, and maximum of the defined area pixel values.

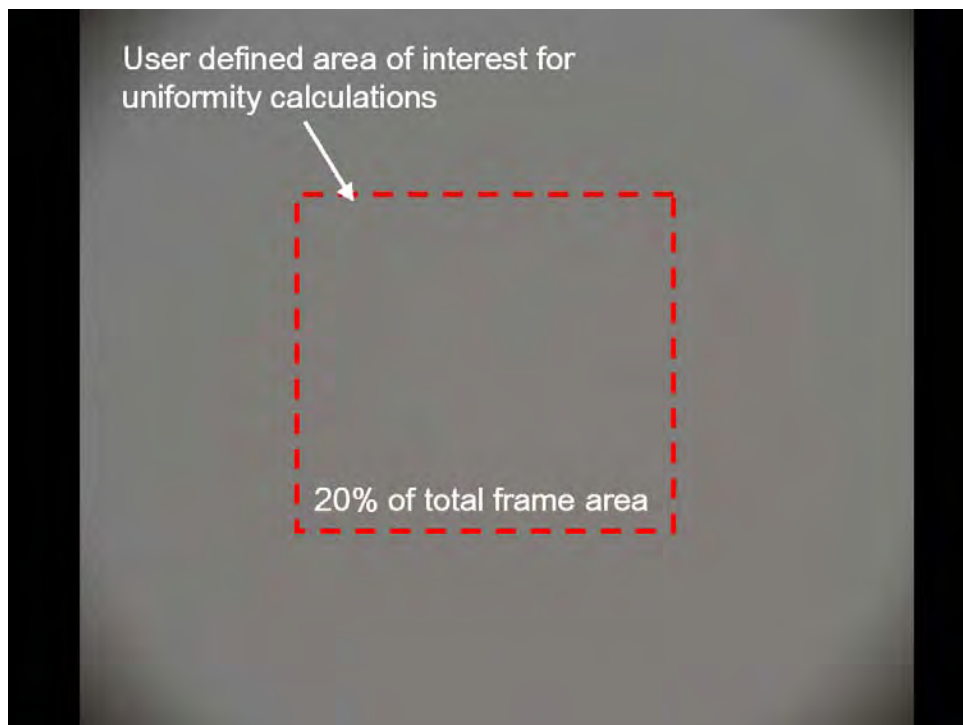


Figure 4. Uniformity Test Image

Intrascene Dynamic Range

Intrascene dynamic range is a measure of usable imaging depth associated with a single frame. For example an 8-bit monochrome sensor would have a perfect intrascene range of 256. That is to say that 256 levels of gray could be resolved across a single image.

This analysis is conducted using an ultra low reflectance etched metal knife edge target. A test image is captured at a luminance level approximately 90% of UUT saturation. The signal area is defined as a 100x100 pixel area within the light section of the half-moon. The background is a 100x100 pixel area within the dark section. See Figure 5. Using EO TestLab the mean pixel value percentage is calculated for each sampled area.

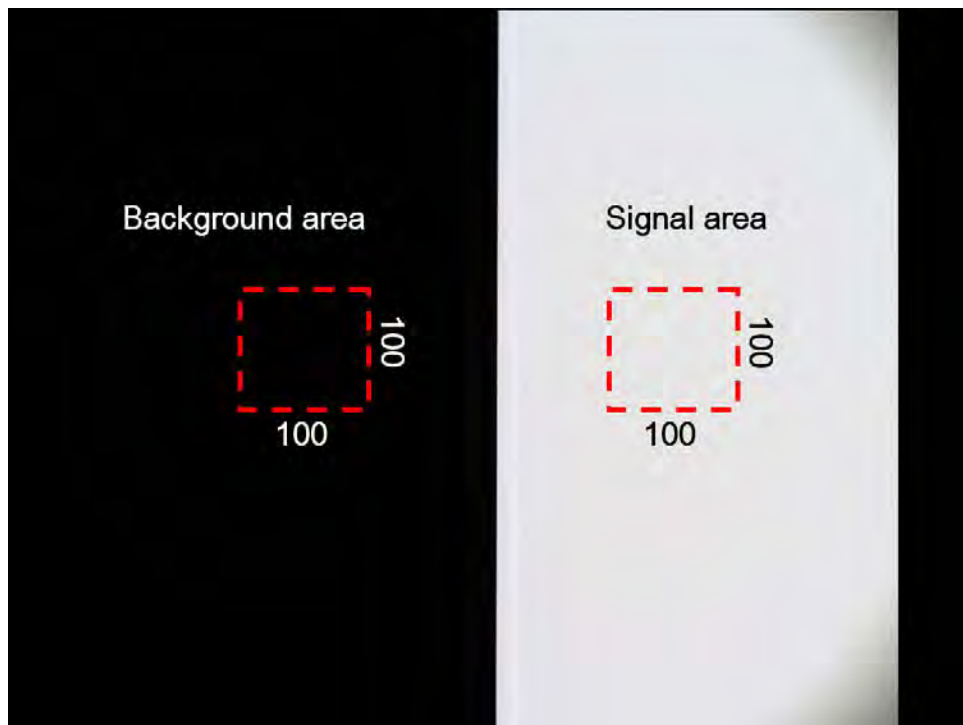


Figure 5. Intrascene Dynamic Range Test Image

The background is normalized for full range by multiplying it by the inverse of the signal value. The reciprocal of this normalized background is the intrascene signal ratio. See Equation 1. Usable grayscale steps are calculated by subtracting the product of the total pixel depth and the normalized background from the total pixel depth. See Equation 2.

Equation 1. Intrascene Signal Ratio

$$\frac{1}{\left(\frac{1}{Signal}\right)Background} = IntrasceneSignalRatio$$

Equation 2. Usable Grayscale Steps

$$TotalDepth - \left(\frac{1}{Signal}\right)Background \bullet TotalDepth = UsableGrayscaleSteps$$

Signal to Noise Ratio / Sensitivity

Sensitivity of a camera is defined as the luminance level in which signal to noise ratio (SNR) is equal to unity. This test is conducted using an ultra low reflectance etched metal knife edge target. Various images of the target are collected over the operating luminance range of the imager.

All frames are analyzed individually by EO TestLab to determine SNR. The signal area is defined as a 100x100 pixel area within the light section of the half-moon. The background is a 100x100 pixel area within the dark section. See Figure 6. Average signal level and background levels are calculated by first fitting a second-order polynomial to each sample data line, subtracting this function from each line to remove any trends, then finding the mean of these lines. The difference between signal and background values is the signal value. The square root of the sum of variances from the background region is the RMS noise.

Some imaging systems clamp the background to a uniform black when subjected to a high contrast image such as the knife edge target. In this situation the classical SNR calculation results in an undefined value. For these cases noise is instead derived from the variance in the signal not variance in the background.

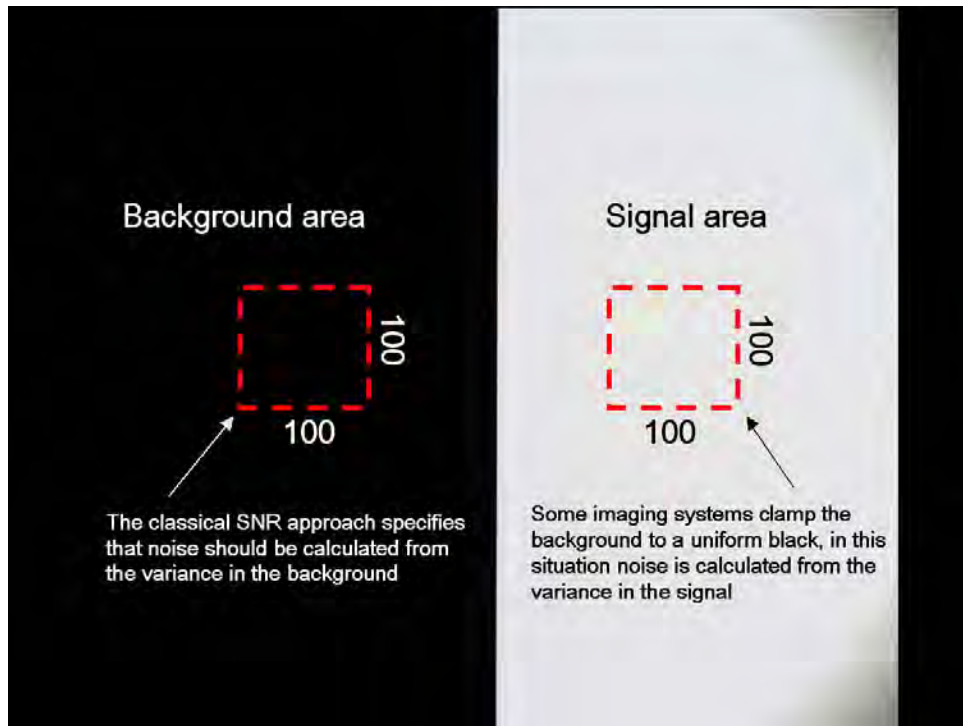


Figure 6. Signal to Noise Ratio/Sensitivity Test Image

All sampled data is plotted as luminance versus SNR. See Figure 7. The shape of this graph is useful in determining the light sensitivity performance characteristics over the camera's full range. A multi-order polynomial trend line is best-fit to the data to allow the unity SNR point to be interpolated and sensitivity to be defined.

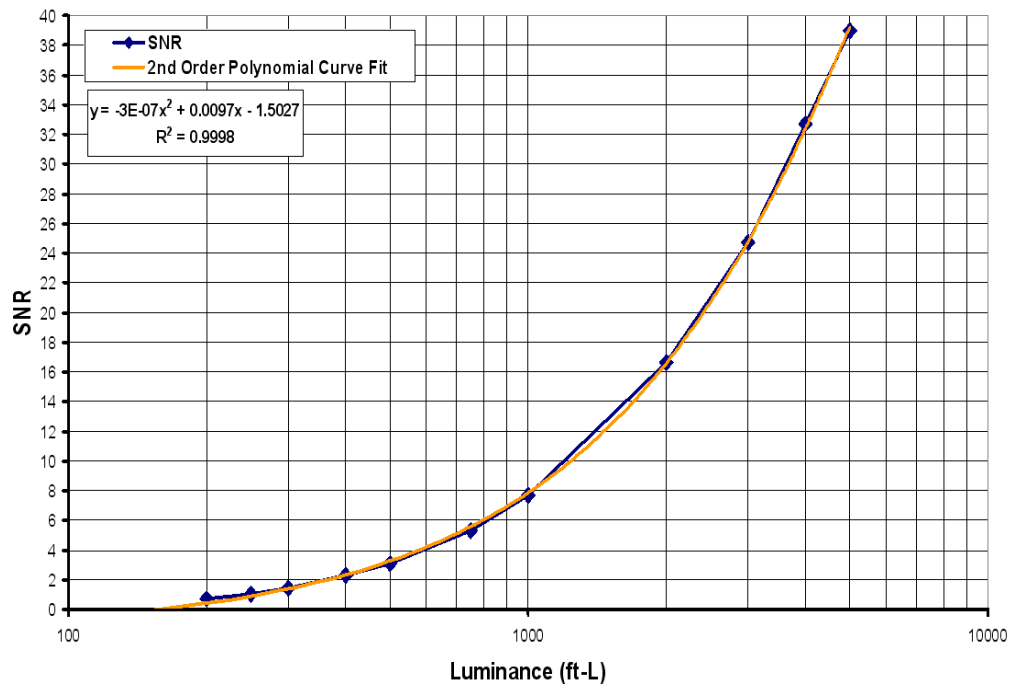


Figure 7. Signal to Noise Ratio Plot

Modulation Transfer Function

The modulation transfer function (MTF) is an objective test used to measure spatial resolution in terms of percent modulation per cycles per millimeter. This test is fully computational and is based on the edge spread function (ESF) of a knife edge image.

This analysis is conducted using an ultra low reflectance etched metal knife edge target. A test image is captured at a luminance level approximately 90% of UUT saturation. The area of interest is defined as a square centered on the edge encompassing 10% of the total frame area. See Figure 8. The pixel values along each horizontal line of the sample are normalized and plotted against horizontal position as the ESF. Differentiating the ESF yields the line spread function (LSF). Finally the MTF is calculated by taking the Fourier Transform of the LSF. The average MTF of all the horizontal lines is reported as the sampled area MTF.

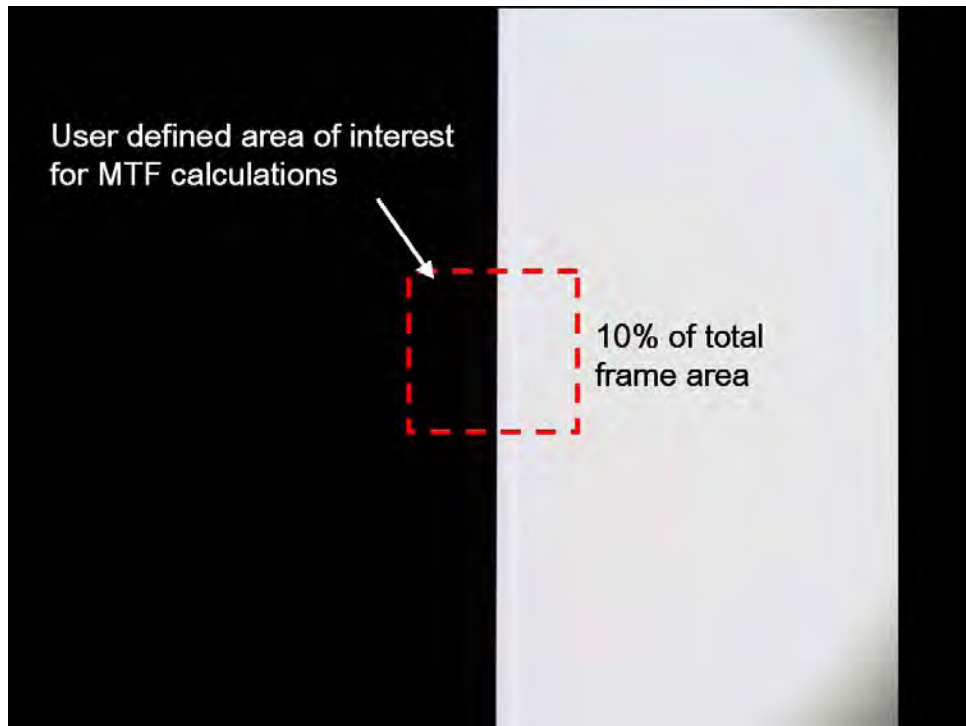


Figure 8. Modulation Transfer Function Test Image

The result of the MTF is a plot of resolution in cycles per millimeter versus modulation percentage. See Figure 9. Even though the human eye can often detect much less, MTF results are typically reported as the resolution at 50% modulation.

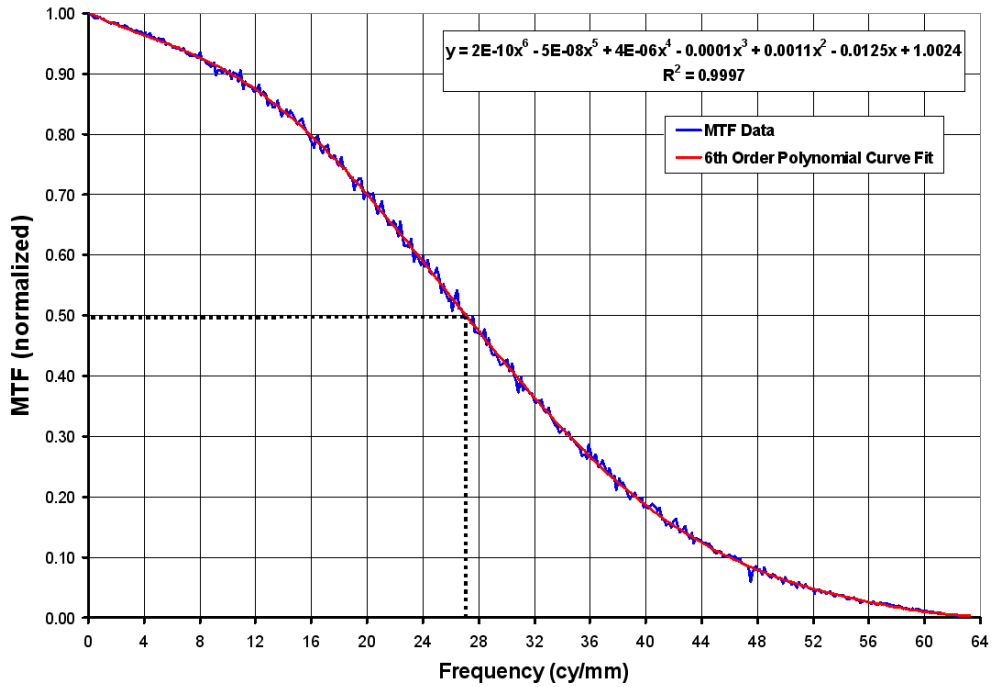


Figure 9. Modulation Transfer Function Plot

Interpreting Results

Resolution and sensitivity are two of the most important specifications of an imaging system. Physics dictates that large pixel size arrays can collect more light and thus be more sensitive, while small pixel size arrays can be more densely packed and provide higher resolution. By analyzing the SNR and MTF plots of various sensor geometries this tradeoff becomes apparent.

Digital cameras employ complex amplification circuitry and extensive image processing routines in an attempt to achieve both a sensitive and high resolution system. Imagers that rely heavily on gain to boost low light scenes into viewable images will become evident when reviewing the SNR plot. With an increase in gain most often comes a corresponding increase in noise thus canceling out any amplifier driven apparent sensitivity improvements. The best sensitivity is achieved by the camera with the highest signal to noise ratio at the lowest light level.

The MTF plot conveys spatial resolution in terms of frequency versus modulation percentage. MTF tests a sensor's ability to resolve a sharp, high contrast straight edge. Image sharpening routines can increase MTF results by sacrificing image depth, often driving sections of the image into saturation. This test must be applied to an unsaturated image, verifying that the image has not been over sharpened. The best resolution is achieved by the camera with the highest modulation percentage at the highest spatial frequency.

Applications

Analog Replacement

When attempting to replace a film based camera with a digital system the end user must be provided with detailed specifications on each imager. Some parameters can be directly compared while others are more esoterically defined. For example the resolution of a analog camera can be defined by the resolvable line pairs per millimeter of the film. While in a digital camera the sensor pixel count is often the only reported resolution specification. Tuned circuitry and software routines make digital sensors highly adaptable imagers yet at the same time they create a system that proves difficult to characterize. A comprehensive test set is required to determine meaningful performance data of these types of systems.

Digital Comparison

Digital cameras often share similar specifications yet performance data can vary widely. Contrasting test methods and reporting techniques can skew advantages and shortcomings of systems. A standard test set is the only way to effectively compare multiple imagers virtually side by side.

Maintenance

Cameras that are subjected to unstable or hostile conditions need to be reevaluated at regular intervals to determine if any damage has occurred that may compromise the performance of the system. A database should be maintained to provide a means to track the progression of camera performance from the optimal initial purchase state through field use to the current condition. An abbreviated version of the comprehensive test set such as an MTF measurement and three SNR points would provide an efficient means to quickly prove out a digital camera system.