

Digital Darkroom Science in the Forensic Laboratory:
Sensitometry and DCS Professional Digital Cameras

Barry D. Bullard, Ph.D., P.E.

Professor and Institute Chief Scientist

Indiana University-Purdue University at Indianapolis

Institute for Forensic Imaging

Herbert L. Blitzer

Executive Director

Institute for Forensic Imaging

Introduction

High quality photographic digital image capture and image processing is becoming a technically attractive and cost effective alternative to conventional photography in the forensics laboratory. Several papers have been published on applications of digital image techniques in forensics, particularly in the fields of latent fingerprints and questioned documents (Bijhold 1955, Birge & Bullard 1995, Watling 1993). A digital image capture and image processing workstation consisting of a professional high resolution digital camera offers the forensic lab new opportunities to increase work quality and productivity.

Over the past two years, the Institute for Forensic Imaging (IFI), located on the Indiana University-Purdue University at Indianapolis (IUPUI) campus, has developed, installed, and tested two state-of-the-art digital imaging darkrooms, and has conducted several research and development projects in the application of the image capture/processing workstations for forensics.

This paper describes a recent project conducted at the Institute to characterize the sensitometric response of several DCS-Class professional digital imaging cameras, these included:

- DCS 420 monochrome (DCS420m)
- DCS420 RGB color (DCS420c)
- DCS 460 RGB color (460c), and
- Canon EOS-DCS 3 RGB color (EOS-3).

Image Formation and Subject Luminance Range

When the shutter release is activated on a camera, two factors, light intensity and time, combine to produce the image exposure on the image plane of the camera. Although a single exposure setting (i.e. single f-stop and shutter speed) is used to make the exposure, the imager in the camera (film or solid-state) does not receive a single, uniform exposure of light over its entire imaging area. The subject being imaged can reflect a wide range of light intensities, or luminance values toward the camera lens for a given exposure setting. The range of light intensities that a given subject reflects toward the camera is called the *subject luminance range*, but is usually referred to as the *subject brightness range*, and its abbreviation, SBR (Davis, 1993). "SLR" is generally not used for subject luminance range because it means single-lens reflex to most photographers.

The famous American landscape photographer Ansel Adams devised what he called the 'zone system' to characterize subject SBR into everyday practice. The essence of the system is that the brightness of a subject image, from its deepest shadow to brightest highlight, is related to a set scale of zones. The zone system uses nine gray zones (I-IX) plus total black (0) and total white (X). Zone V is mid-gray, the equivalent of an 18% gray reflectance card. Each zone represents half or twice as much subject luminance (1-stop) relative to its neighbor zone.

Having defined the full SBR range as Zone 0 to Zone X, Ansel subdivided the total range further into two sub-ranges. The *dynamic* sub-range consists of Zones I through IX, and represents SBR values that convey "information" about the image. Finally, the *textural* sub-range, consisting of SBR values located in Zones II through VIII, convey qualities of texture and substance in the image (Schaefer, 1992). It is very unusual for an image to span the total range of 10 zones. It is a general, industry-wide consensus that the normal subject luminance range is about 7-stops (Langford 1994). With correct metering at Zone V, an imaging system with a balanced 7-stop SBR dynamic range would capture all of the subject luminance texture range (6-stops), and most of the image's dynamic range (8-stops).

SBR Calibration Targets and Density

To measure the SBR dynamic range of a given imager (i.e. camera), a target image is created with several known luminance values. Targets are transmittance or reflective in type. Transmittance targets control the amount of light that is allowed to pass through them, such as film. Reflective targets absorb light that is applied to it, thus "blocking" the reflected light to the imager (i.e. ink & paper).

A common measure of luminance (or brightness) in photography is *density*. By definition, density is the common log of opacity, which is the reciprocal of transmittance. Transmittance is defined as the ratio of the amount of light striking an object to the amount of light allowed to pass through the object. For example, if 100 units of light are directed toward a layer of film and 20 units of light pass through the film, the transmittance of the film is 20/100 or 20%. The opacity would be 5 (1/0.2), and the density of the film would be 0.7 (log 5). One would note that a density increase of 0.3 {log (1/0.5)} represents "half the light", or the equivalent of one f-stop, or doubling of the camera shutter speed. Table 1 illustrates the luminance relationship

between density, f-stops, shutter speeds, and film ISO for several common settings.

To test an imaging system for a luminance dynamic range of 8-stops, a target density dynamic range of 2.4 would be required (0.3 x 8). Several density targets within this range are available from commercial vendors, such as the Kodak IT-8. Reflective targets generally can not produce density ranges greater than about 2.5 due to limitations in paper and ink technology. Transmittance targets can be produced with a maximum useful density of approximately 4.0.

In addition to using industry standard targets for this research project, the Institute also developed a custom transmittance target with a calibrated density range of 3.6 (12-stops).

Full-Frame CCD Imagers and DCS Class Professional Digital Cameras

The DSC class of professional digital cameras offered by Kodak and Canon utilize a full-frame charge-coupled device (CCD) chip for the light sensing imager. Table 2 lists some of the key specifications for the DSC cameras tested under this research project.

The luminance dynamic range of a silicon-based CCD imager is based on the ratio of an array element's (pixel) "well" capacity to store electrons and the readout noise level of the imager. The readout noise level is analogous with the base+fog level of film. Exceeding the capacity of a given pixel's "well" generates excess electrons resulting in blooming and overexposure of the image. Therefore, CCD imaging cameras exhibit S-shaped D-H curves similar to those of film or paper with range limiting "toes" and "shoulders".

Figure 1 illustrates the "S-shape" sensitometry response curve for a hypothetical CCD imaging sensor. The vertical axis of the graph represents the reported average 8-bit grayscale value (0-255) for each luminance area of the target image as recorded by the sensor. A reported value of 0 equals' pure black and 255 equals' pure white.

Sensitometry Response of Tested DCS Cameras

Figure 2 shows the sensitometric response of a tested DCS 420m digital camera using the 12-stop subject luminance range target.

Zone V metering point of the camera was set to the approximate $d=1.4$ midpoint of the test target.

The DCS 420m exhibits a constant slope response profile of approximately 2-stops around the Zone V midpoint for a total linear response dynamic range of approximately 4-stops. The camera has a very "hard" highlight saturation response as illustrated by the rapid decrease of the curve slope toward decreasing density from the midpoint after 2-stops.

In contrast to its "hard" saturation response, the camera exhibits a very "soft" response to shadows, as illustrated by the long tail of the curve as density increases beyond the mid-point constant slope region. A second semi-linear region begins at approximately $d=2$, and continues to the limit of the test target ($d=3.59$). It should be noted that the sensitivity of the camera to change in density (i.e. slope of the curve) in this second region is approximately one-fourth that of the camera's response in the mid-point region.

Figure 3 shows the sensitometric response of a tested DCS 420c digital camera for the same 12-stop test target. The original 8-bit three channel (RGB) camera image was converted to a single 8-bit channel grayscale image for sensitometry analysis. Review of Figure 2 indicates a similar response as the 420m, but with a slightly "softer" saturation region. This results in an additional 1-stop of usable highlight dynamic range. However, the sensitivity of the camera in this upper 1-stop region is approximately 50% relative to the camera's sensitivity in the mid-point linear region.

Figures 4 and 5 illustrate the sensitometric response of the DCS 460c and DCS EOS-3 respectively. Each camera exhibits similar 4-to-5 stop linear dynamic range and long shadow tails as noted earlier for the DCS 420 m & c models.

Conclusions

It is generally accepted in the industry that to capture all the tones of a typical subject image, the capturing imager should have a minimum tonal dynamic range of 7-stops ($d=2.1$). Current professional film and paper support the 7-stop requirement, with some films capable of 8-to-9 stops.

The objective of this research project was to characterize the sensitometric, or tonal, dynamic range response of several DCS-

class professional digital cameras. Since these cameras use solid-state CCD technology for image capture as opposed to film technology, their sensitometry response will be unique and uncorrelated relative film or paper response.

Using calibrated targets with known luminance values, each DCS camera was tested to determine its maximum tonal dynamic range response. Results indicated all four tested cameras exhibited similar performance, which included a 4-to-5-stop linear region, strong to moderate highlight saturation sensitivity, and a long tail response in the shadow regions.

To achieve non-saturated 7-stop dynamic range with these cameras, it would be necessary to underexpose the setting on the camera to effectively move Zone V toward the shadow region by one or two stops to create an additional stop on the highlight side of the mid-point. This will result in using part of the non-linear region in the shadow area of the camera's response. Digital enhancement of the captured image can be used to correct for the original non-linear response of the camera to effectively produce a consistent response 7-stop dynamic range imager.

Table 1
Luminance Relationships Between
Relative Density, F-stops, Shutter Speed, and Film ISO

Relative Stops*	0	1	2	3	4	5	6	7	8	9
Shutter speed	1	1/2	1/4	1/8	1/16	1/32	1/64	1/128	1/256	1/512
f-number	1.4	2	2.8	4	5.6	8	11	16	22	32
ISO speed	9600	4800	2400	1200	800	400	200	100	50	25
Relative Density*	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7

* Changing one: Shutter Speed, f-number, or ISO Speed

** As a function of Relative Stops

Table 2
Selected Parameters of Tested DCS Pro Cameras

CAMERA MODEL	SLR CAMERA BODY	CCD ARRAY IMAGE SIZE (wxh)mm	UNIT PIXEL SIZE (microns)	TOTAL ARRAY PIXEL SIZE (wxh)
DCS 420 (m&c)	NIKON N90	13.7x9.1	9	1524 x 1012
DCS 460c	NIKON N90	27.6x18.4	9	3060 x 2036
DSC EOS-3	CANON EOS-1	20.5x16.4	16	1280 x 1024

Figure 1

Sensitometry Response of a
Hypothetical CCD Imaging Sensor

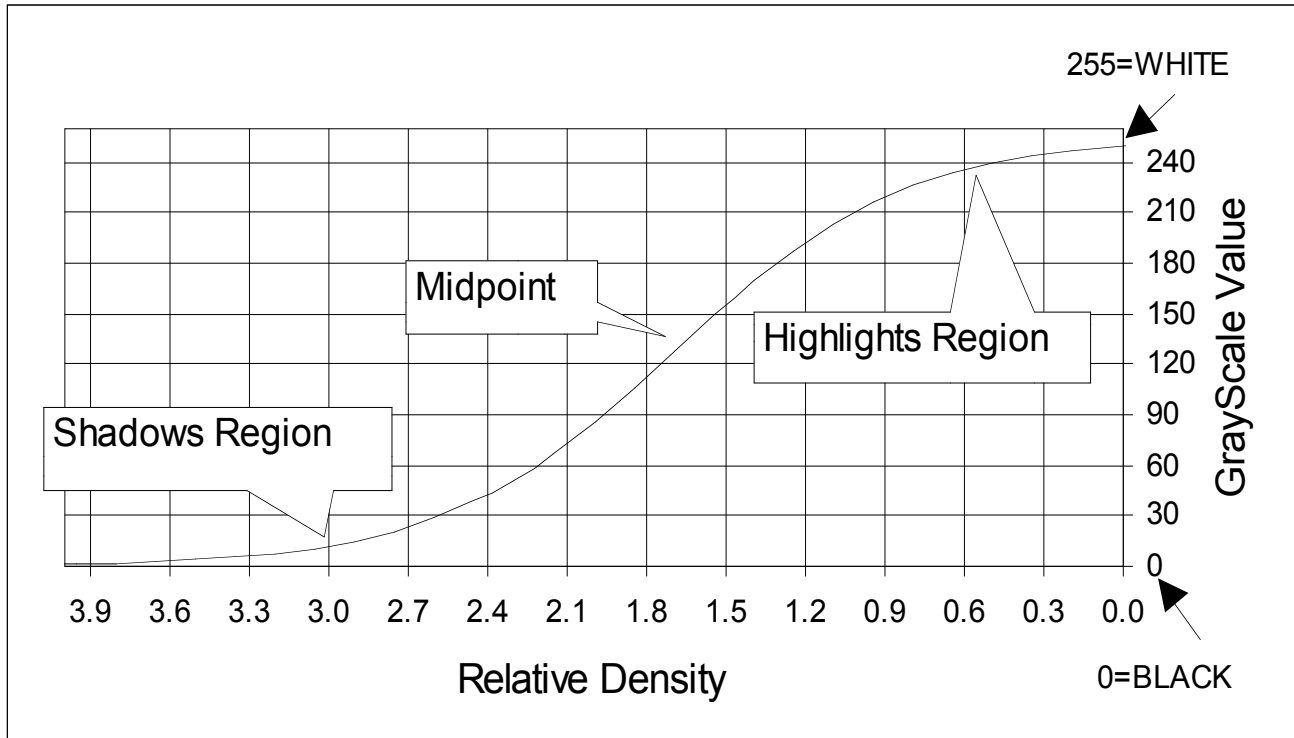


Figure 2
DCS 420m Sensitometry Response

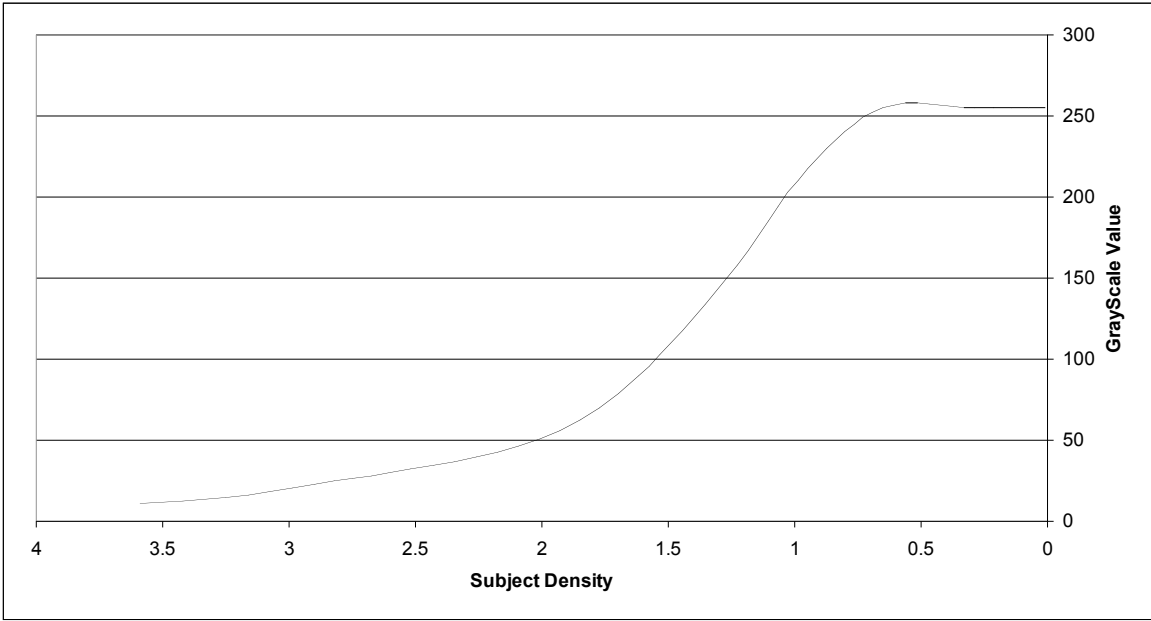


Figure 3
DCS 420c Sensitometry Response

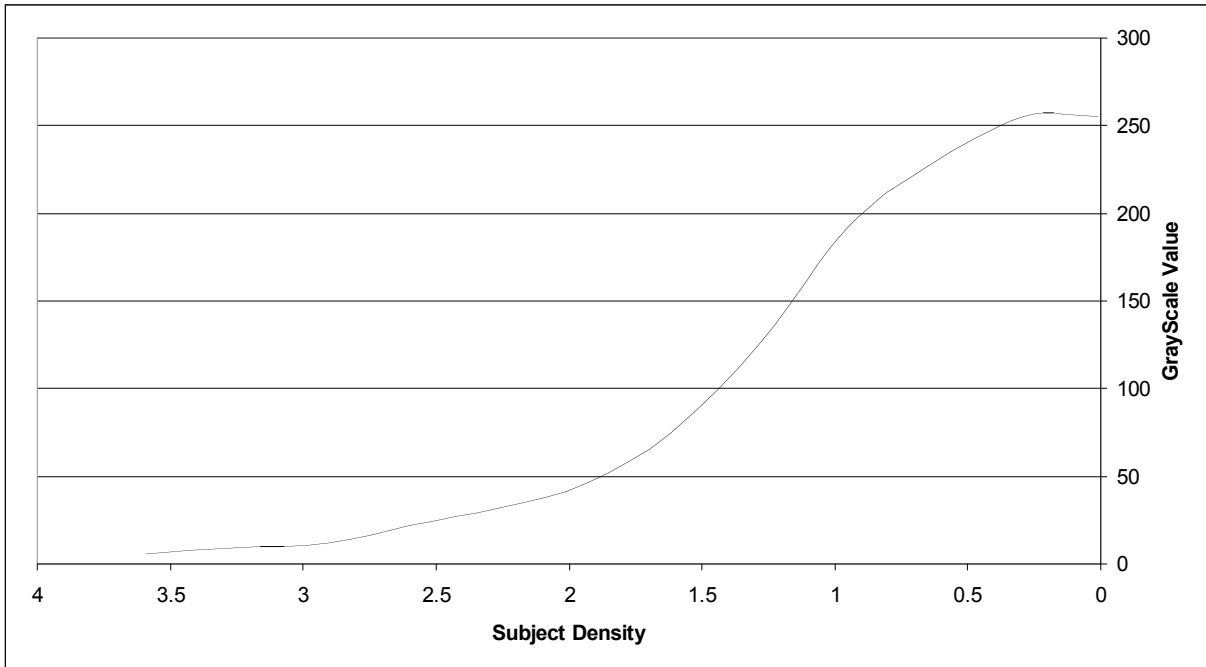


Figure 4
DCS 460c Sensitometry Response

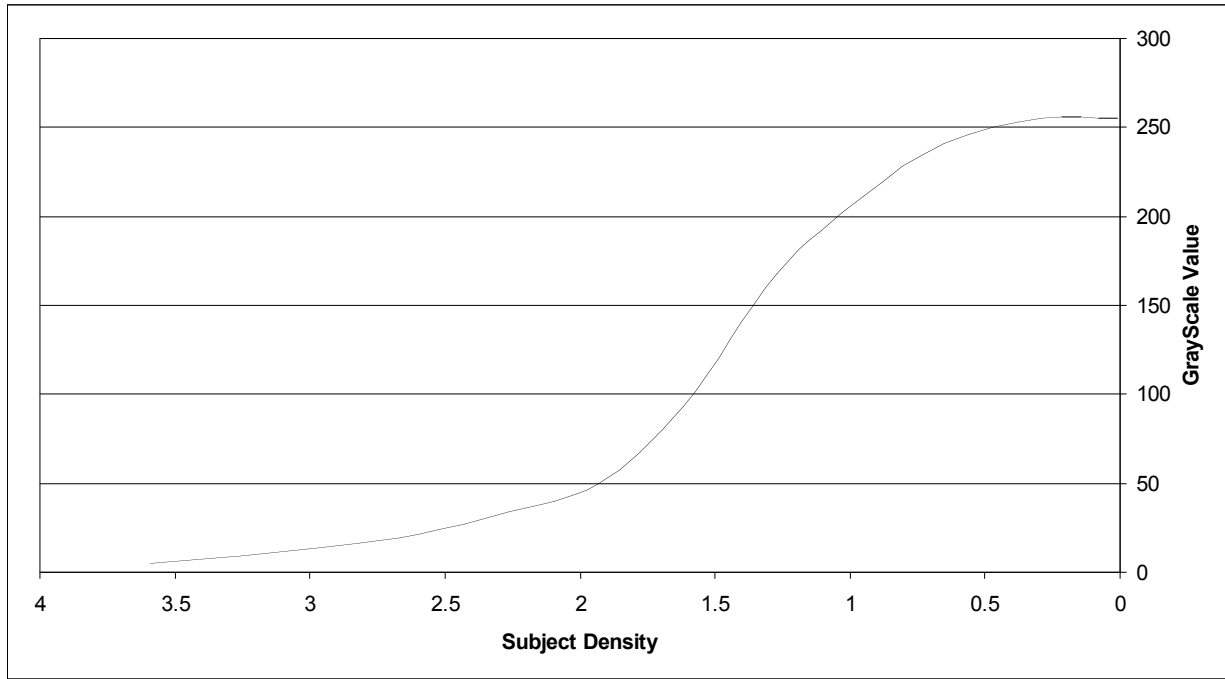
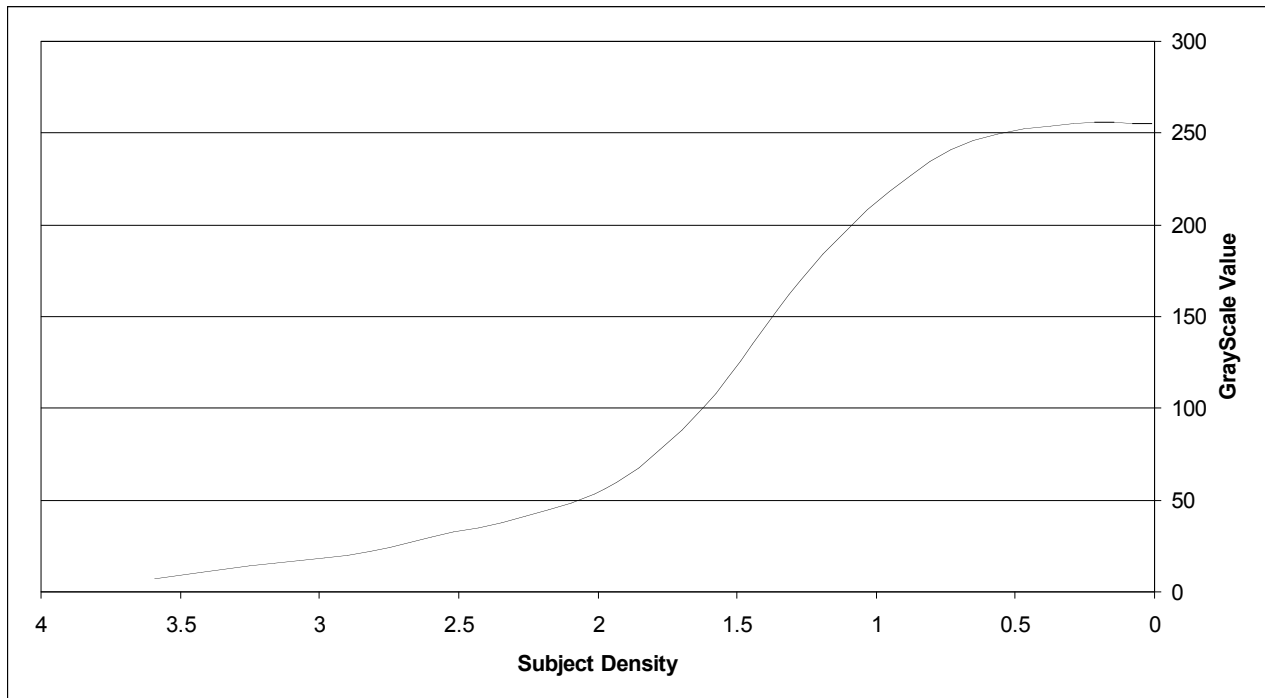


Figure 5
DCS EOS 3 Sensitometry Response



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