Digital color cameras - 1 - Response models

Poorvi L. Vora, Joyce E. Farrell,
Hewlett-Packard Laboratories, 1501 Page Mill Road, Palo Alto, CA 94304
Phone: (415) 857-2457, Fax: (415) 857-4691
Email: { poorvi, farrell }@ hpl.hp.com
Jerome D. Tietz, David H. Brainard
Dept. of Psychology, University of California at Santa Barbara
Santa Barbara, CA 93106
Phone: (805) 893-2011, Fax: (805) 893-4303
Email: {tietz, brainard }@ psych.ucsb.edu

Abstract

This report describes and verifies response models for digital color cameras. We investigated two specific cameras, the Kodak DCS-200 and the Kodak DCS-420. For each camera, we measured the RGB camera responses for various combinations of source wavelength, source intensity, and camera exposure duration. We also measured the dark noise for each camera. We found that the DCS-200 is characterized by a linear intensity-response function, while the DCS-420 requires the addition of a static non-linearity. Our models may be used to process raw camera responses when intensity-calibrated sensor data are required. Possible applications include color balancing, demosaicing, and image restoration.

1 Introduction

The processing of digital color camera data (e.g. color correction, demosaicing, and image restoration) often depends on the assumption that the camera sensor responses are linear with respect to source intensity. This *response linearity assumption* is also closely related to the use of a single spectral sensitivity function to characterize how the camera responds to sources with different spectral power distributions. Before applying algorithms that depend on the response linearity assumption, it is important to verify that the assumption holds. If the assumption is violated, it is then desirable to find a way to correct the data for any non-linearities.

The light sensors in many modern digital cameras are based on Charge-Coupled Device (CCD) or Active Pixel Sensor (APS) technology. These devices are known to have linear intensity-response functions over a wide operating range [1] and thus the response linearity assumption is plausible. The overall camera system may not exhibit the underlying device linearity, however. For example, there may be a non-linear mapping between the raw sensor output and the digital responses actually available from the camera. Such a non-linearity might be designed into a camera system if the dynamic range of the sensor itself is larger than that of the camera. This is the situation with the Kodak DCS-420. It employs a 12-bit internal data representation but its standard control software provides only 8-bits of precision.

This report begins (section 2) with a description of two response models for digital color cameras. The first incorporates the response linearity assumption; the second extends the first by adding a static non-linearity. We then (sections 3 and 4) describe the measurements we made to determine whether our models described the performance of the Kodak DCS-200 and DCS-420 cameras. We also (sections 5 and 6) discuss and measure response variability for the two cameras. We conclude (section 7) with some discussion.

2 Camera response models

We consider two camera response models. The first is the *linear response model.* For this model, the camera response for a pixel of the i^{th} sensor type pixel is given by

$$r_i \; = \; e \int_{\lambda_l}^{\lambda_h} s_i(\lambda) i(\lambda) d\lambda \; + \; n_i \tag{1}$$

where $s_i(\lambda)$ is the spectral sensitivity of the i^{th} sensor type, $i(\lambda)$ is the incident power density per unit time at wavelength λ, e is the exposure duration, and n_i is a normal random variable. Typically there are three sensor types (red, green, and blue) so that $i = 1, 2, 3$. The mean and variance of n_i describe the dark noise and response variability for the i^{th} sensor type. The limits λ_l and λ_h are the wavelength limits beyond which the spectral response of the sensor is zero.

Our second model is the *static non-linearity model.* For this model, the camera response for a pixel of the i^{th} sensor type pixel is given by

$$r_i \; = \; \mathcal{F}(e \int_{\lambda_l}^{\lambda_h} s_i(\lambda) i(\lambda) d\lambda \; + \; n_i) \tag{2}$$

where $\mathcal{F}$ is a monotonically increasing non-linear function.

3 Camera response to intensity variation

We measured the intensity-response functions of the Kodak DCS-200 and the Kodak DCS-420 cameras. The DCS-200 contains an 8-bit CCD array while DCS-420 contains a 12-bit CCD array. For both cameras, images were obtained with a Macintosh host computer using 8-bit drivers provided by Kodak. The camera apertures were kept fixed (at f5.6 for the DCS-200 and at f4 for the DCS-420) for all experiments described in this report.

Our basic procedure was to take pictures of a white surface (PhotoResearch RS-2 reflectance standard) when it was illuminated by light of different intensities. We illuminated the surface with light from a tungsten source passed through a grating monochrometer (Bausch & Lomb, 1350 grooves/mm) and varied the intensity by placing neutral density filters in the light path. We used a spectrophotometer (PhotoResearch PR-650) to measure directly the spectrum of the light reflected to the camera. Using this set-up, we measured camera intensity-response functions at several exposure durations for both the DCS-200 and DCS-420 cameras.

For each intensity-response series, we assigned an intensity measure of unity to the light reaching the camera when no neutral density filters were in the light path. The intensity of other test lights in the series was defined relative to the intensity of this light. The relative intensity was determined by finding the scale factor that brought the maximum-intensity spectrum into agreement with the spectrum of the test light.

Both the DCS-200 and DCS-420 have a resolution of 1524×1012 and the RGB sensors for each camera are arranged in a Bayer mosaic pattern [3]. To obtain sensor data from the camera images we subsampled the camera output using this Bayer pattern. To estimate the mean value of the (dark) additive noise, we acquired images with the lens cap on the camera.

3.1 Kodak DCS-200

For each image, we averaged the R, G, B values over a region of 3000 (60×50) pixels in the center field of the camera. We measured three intensity-response series, one each at wavelengths of 450, 530, and 600 nm. For each wavelength, the exposure duration was chosen so that the light energy was roughly within the dynamic range of the camera. The exposure duration was fixed for all measurements corresponding to one wavelength.

The results are shown in Figures 1-3. The x-axis shows the intensity of the incident light (calculated as described above) and the y-axis shows the camera output value (with the expected value of the noise subtracted). The crosses represent actual data points. The straight lines are fit to the data and constrained to pass through the origin. In fitting the data, we excluded saturated points and points with very low intensities. The good agreement between the data and the fit lines indicate that the

DCS-200 has a linear intensity-response function over most of its operating range.

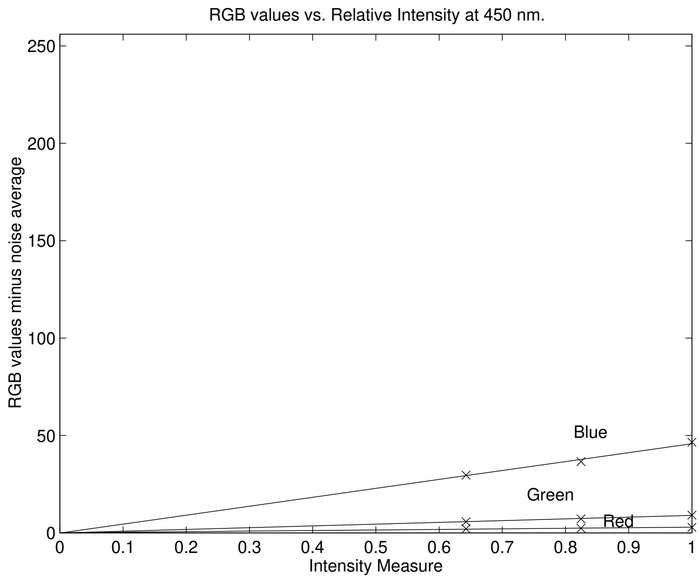

Figure 1: Intensity-response - DCS-200 - 450 nm., 2 sec. exposure.

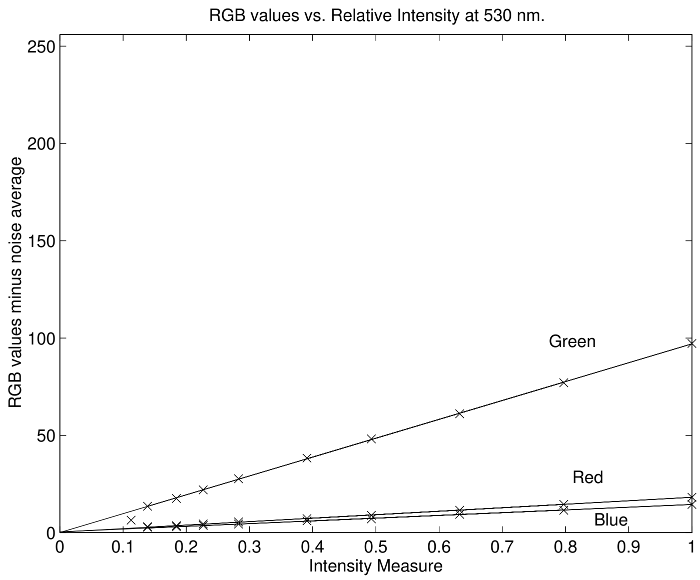

Figure 2: Intensity-response - DCS-200 - 530 nm., 0.5 sec. exposure.

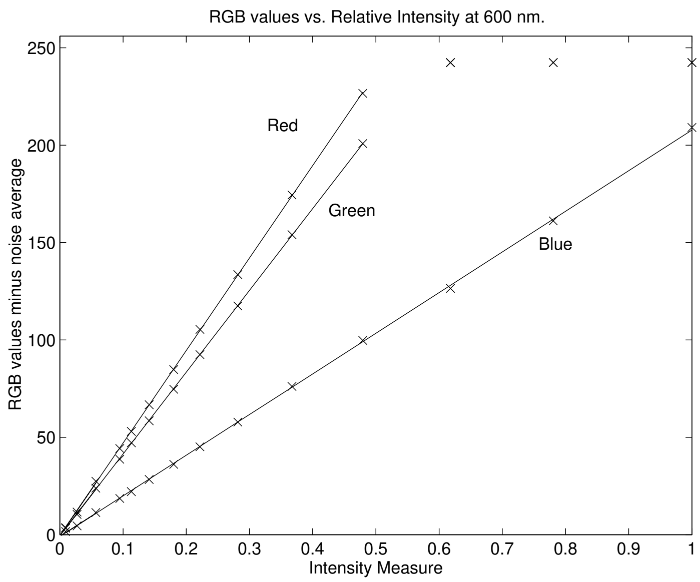

Figure 3: Intensity-response - DCS-200 - 600 nm., 2 sec. exposure.

3.2 Kodak DCS-420

As an initial test, we roughly calculated the average green sensor (G) value at the center of the image field for a series of images taken under 525 nm. illumination. Figure 4 shows the intensity-response function. The x-axis shows the intensity of the incident light (calculated as described above) and the y-axis shows the camera output value (with the expected value of the noise subtracted). The crosses represent actual data points. The relationship between intensity and response is clearly non-linear. We explore a possible cause for this non-linearity in the 12-to-8-bit reduction in the image acquisition software. In this case the intensity-response function may be modeled by equation (2).

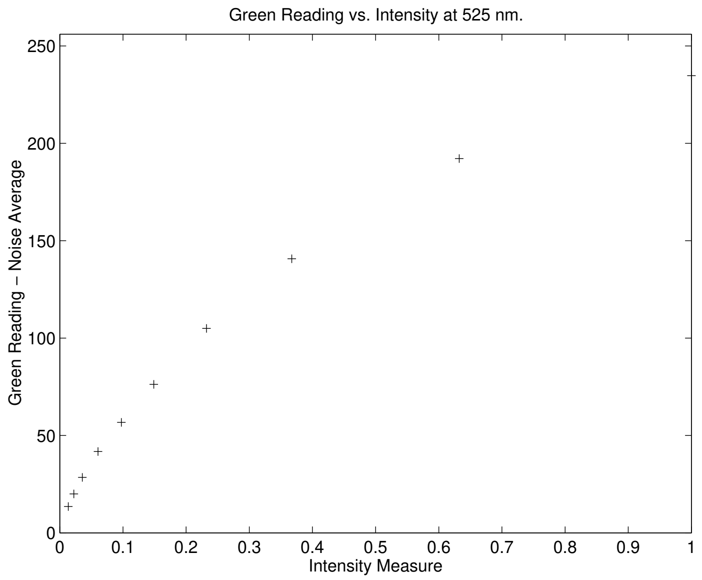

Figure 4: Intensity-response - DCS-420 - 525 nm., 1 sec. exposure.

We performed additional measurements at various wavelengths and exposure durations. We extracted the average R, G, and B sensor readings in the center 64×64 image region. The results are plotted in Figures 5 - 8. In these figures, the expected value of the dark noise has not been subtracted from the camera output. Each of the figures shows a non-linearity similar to that seen in Figure 4.

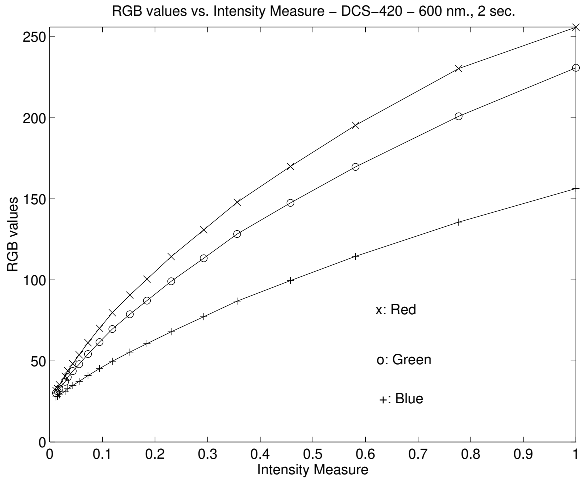

Figure 5: Intensity-response - DCS-420 - 600 nm., 2 sec. exposure.

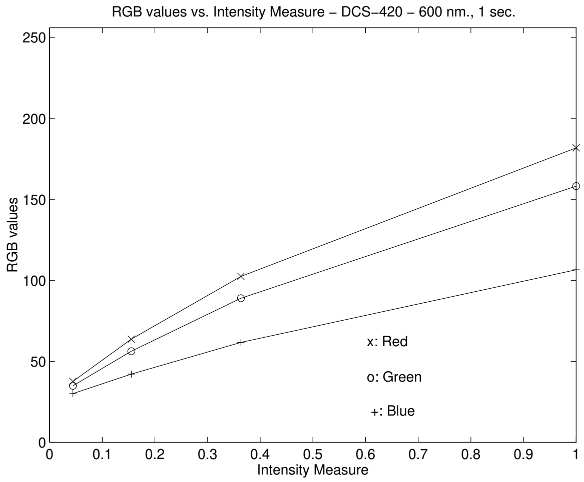

Figure 6: Intensity-response - DCS-420 - 600 nm., 1 sec. exposure.

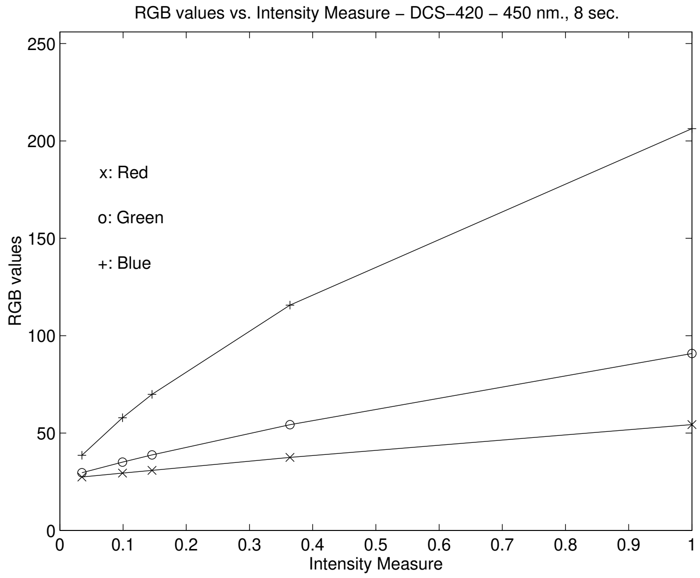

Figure 7: Intensity-response - DCS-420 - 450 nm., 8 sec. exposure.

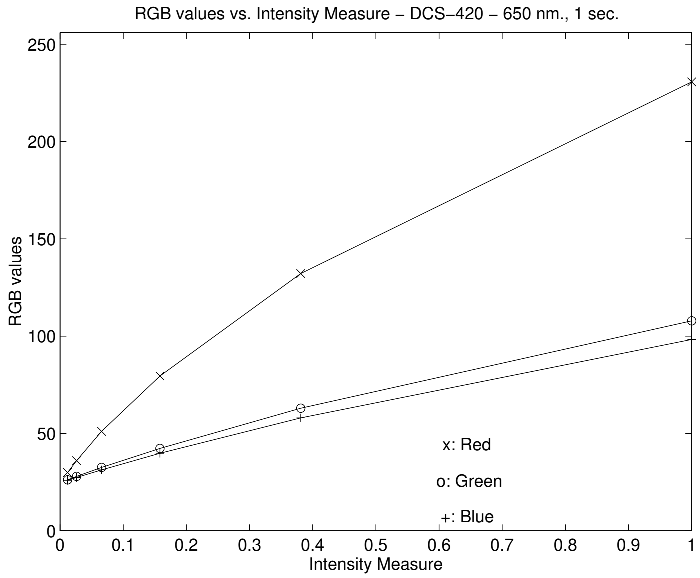

Figure 8: Intensity-response - DCS-420 - 650 nm., 1 sec. exposure.

4 Camera response to variation in exposure

4.1 Kodak DCS-200

To test for linearity with exposure duration, we took pictures of the white surface under fixed illumination at different exposure durations. We did this with narrow band illumination at 470, 530, 570 and 660 nm. Figures 9-12 show the results. As with Figures 1-3, the crosses represent actual data points with the expected value of the noise subtracted and the lines are fits constrained to pass through the origin. The slight variation from linearity may be due to the fact that the shutter exposure time is not controlled accurately.

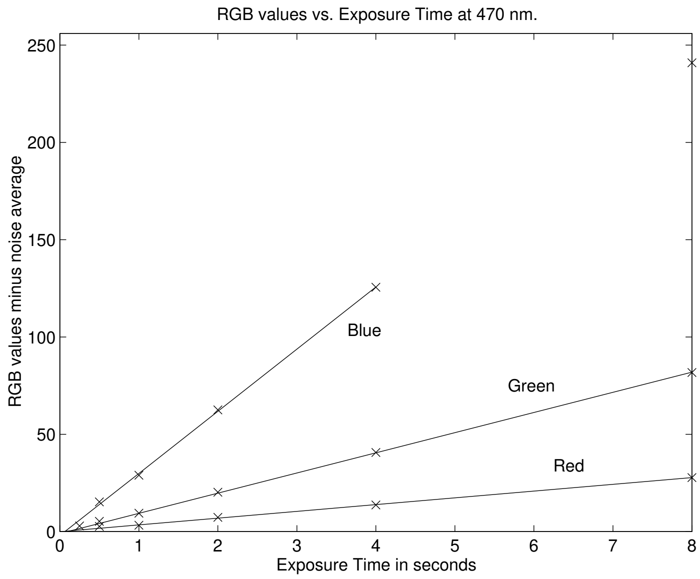

Figure 9: Linearity tests wrt exposure - DCS-200 - incident radiation at 470 nm.

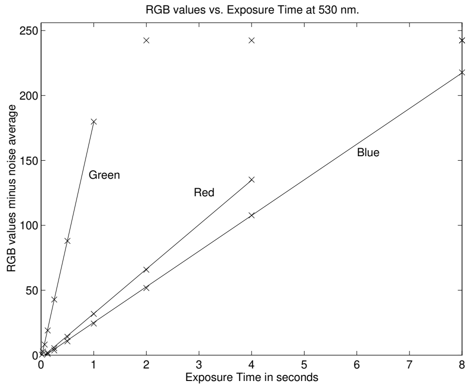

Figure 10: Linearity tests wrt exposure - DCS-200 - incident radiation at 530 nm.

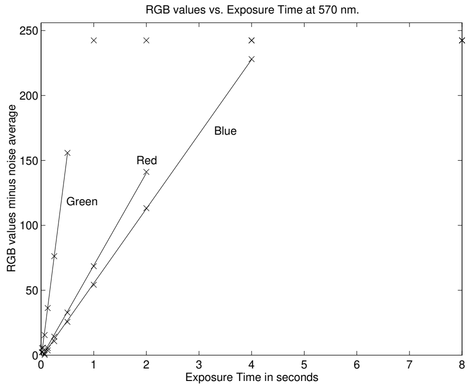

Figure 11: Linearity tests wrt exposure - DCS-200 - incident radiation at 570 nm.

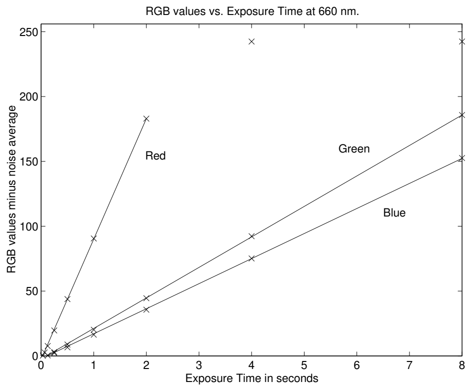

Figure 12: Linearity tests wrt exposure - DCS-200 - incident radiation at 660 nm.

4.2 Kodak DCS-420

As the DCS-420's intensity-response function is not linear, it would be surprising if its output were linear with exposure duration. We roughly calculated the average green sensor (G) value at the center of the image field for images of the white surface taken at various exposure durations for 525 nm. illumination. Figure 13 shows the results with average noise subtracted (x's) overlaid on the data of Figure 4 (replotted as o's). The x-axis represents exposure duration relative to one second and intensity relative to unity. The two readings corresponding to one second and unit intensity are replications of the same illumination condition, so that no scaling of the data were required. The close agreement between the two curves suggests that the same non-linearity mediates both.

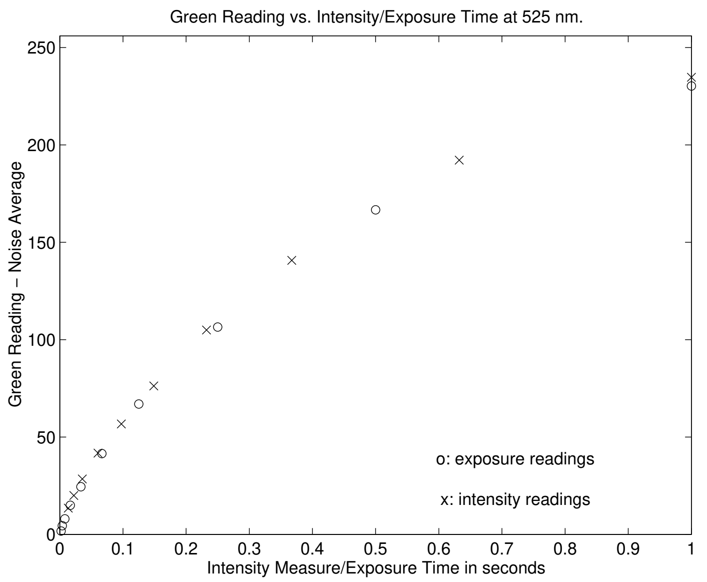

Figure 13: Non-linearity tests wrt exposure - DCS-420 - incident radiation at 525 nm.

5 Response model summary

5.1 Kodak DCS-200

Our data indicate that the linear response model describes the output of the Kodak DCS-200, at least over most of its operating range. The data indicate that the linear model is reasonable over the range 20 to 240. To obtain the parameters describing a single line for all the data, we fit a *calibration line* to the data for the blue sensor readings of Figure 3, DCS-200 readings for incident illumination at 600 nm. and 2 second exposure setting. The range of numerical values for the data is 24.98 to 222.71. The fractional values arise because camera raw data readings are averaged over an area to obtain these values. It is interesting to note that the zero intensity reading corresponds to a camera raw data reading of 12.5, more than one standard deviation below the dark noise mean value (see section 7.1.1).

To verify that the calibration line derived from one intensity response function describes all the data, we can use this line to normalize all of our data and examine it on a single plot. For each measured intensity response function, the intensity measure we used is arbitrary, since we varied both the exposure and wavelength across the different measurements. We can use the calibration line to normalize the data, however. For each data set, we found the highest camera output value in the linear range (below 240) and found its position on the calibration line. We then scaled all the intensity values of that data set by a single normalization scale factor such that the highest camera output value in the linear range would correspond to the intensity factor obtained by looking at the calibration line. This procedure allows us to compare all of our data to the calibration line, as shown in Figure 14. The highest camera output value for each data set lies on the line because of the way the normalization is performed. Data points with values below 240 and above 20 all lie close to the line. Data points with values below 20 or above 240 are plotted with asterisks (*) or lie outside the region shown in the plot.

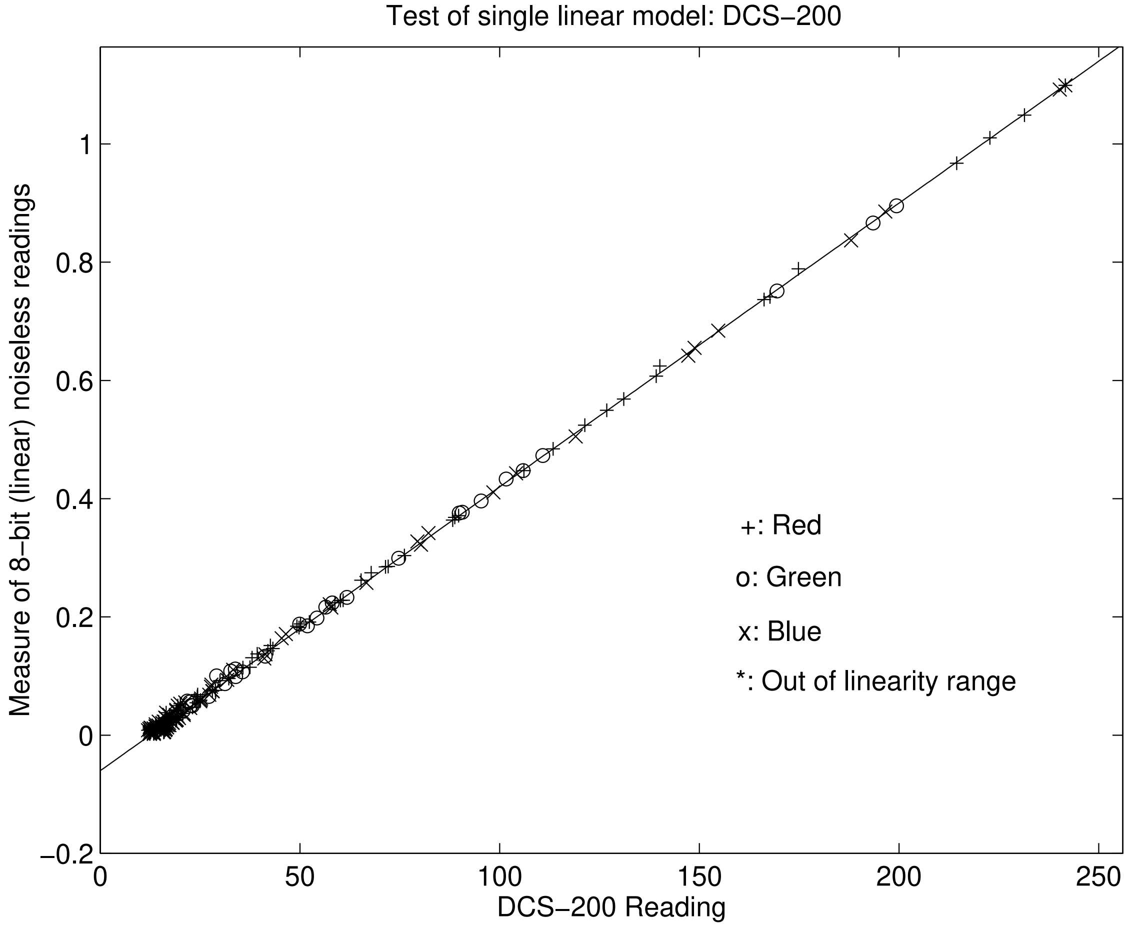

Figure 14: Linearity Map for DCS-200.

5.2 Kodak DCS-420

The Kodak DCS-420 is not linear. To examine whether the static non-linearity response model described its performance, we asked how well a single function $\mathcal{F}$ can describe its output across the conditions we measured. We used the intensity-response series measured for the red sensor at 600 nm. for a 2 sec exposure (Figure 5) as a reference. This series covered most of the dynamic range of the camera. By interpolating and extrapolating the reference, we obtain a *calibration curve* for the DCS-420 that maps between sensor values (0 to 256) to intensities that lie between 0 and 1. This intensity measure is in arbitrary units but may be calibrated to physical units. (We used the MATLAB [4] function 'griddata', which implements an inverse distance method, to do the interpolation and extrapolation.) The result is tabulated in Table 1 and graphed as the line in Figure 15. It represents the value of $\mathcal{F}^{-1}(r) - n$ (or $e \int_{\lambda_l}^{\lambda_h} s(\lambda) i(\lambda) d\lambda$) of equation (2).

We tested the accuracy of the calibration curve by asking how well it described the rest of our data. Each set of acquired data points has a different intensity scale. A value of unit intensity corresponds to the maximum intensity for the shutter speed used for that test. To check if the other acquired data points lie on the calibration curve, the intensity values need to be transformed to a single scale. We calculated the scale factor for the conversion for each data set by using the highest measured output value (which corresponds to a unit intensity for that series), finding its position on the calibration curve, and using the fractional intensity value thus obtained as the scale factor. The data points from all of our intensity-response series as well as the exposure data are plotted in Figure 15 along with the calibration curve. The data all lie along the curve.

Table 1: Static Nonlinearity, DCS-420 - Conversion from 8-bit nonlinear measurements to linearized value.

8-bit Input	Linearized Output	8-bit Input	Linearized Output	8-bit Input	Linearized Output	8-bit Input	Linearized Output	8-bit Input	Linearized Output
0	0	52	0.0519	103	0.1930	154	0.3820	205	0.6280
1	0	53	0.0541	104	0.1960	155	0.3870	206	0.6330
2	0	54	0.0563	105	0.2000	156	0.3910	207	0.6380
3	0	55	0.0585	106	0.2030	157	0.3960	208	0.6440
4	0	56	0.0607	107	0.2060	158	0.4000	209	0.6490
5	0	57	0.0629	108	0.2090	159	0.4050	210	0.6540
6	0	58	0.0651	109	0.2130	160	0.4100	211	0.6590
7	0	59	0.0674	110	0.2160	161	0.4140	212	0.6650
8	0	60	0.0697	111	0.2190	162	0.4190	213	0.6700
9	0	61	0.0720	112	0.2230	163	0.4240	214	0.6750
10	0	62	0.0743	113	0.2260	164	0.4290	215	0.6810
11	0	63	0.0767	114	0.2300	165	0.4330	216	0.6870
12	0	64	0.0792	115	0.2330	166	0.4380	217	0.6920
13	0	65	0.0816	116	0.2370	167	0.4430	218	0.6980
14	0	66	0.0841	117	0.2400	168	0.4480	219	0.7040
15	0	67	0.0865	118	0.2440	169	0.4520	220	0.7100
16	0	68	0.0890	119	0.2480	170	0.4570	221	0.7160
17	0	69	0.0915	120	0.2510	171	0.4620	222	0.7220
18	0	70	0.0940	121	0.2550	172	0.4670	223	0.7280
19	0.0001	71	0.0965	122	0.2590	173	0.4720	224	0.7340
20	0.0005	72	0.0990	123	0.2630	174	0.4760	225	0.7400
21	0.0009	73	0.1010	124	0.2670	175	0.4810	226	0.7470
22	0.0014	74	0.1040	125	0.2700	176	0.4860	227	0.7540
23	0.0019	75	0.1060	126	0.2740	177	0.4910	228	0.7600
24	0.0025	76	0.1090	127	0.2780	178	0.4960	229	0.7670
25	0.0032	77	0.1120	128	0.2820	179	0.5000	230	0.7750
26	0.0041	78	0.1140	129	0.2860	180	0.5050	231	0.7820
27	0.0050	79	0.1170	130	0.2890	181	0.5100	232	0.7900
28	0.0060	80	0.1200	131	0.2930	182	0.5150	233	0.7970
29	0.0072	81	0.1220	132	0.2970	183	0.5200	234	0.8050
30	0.0086	82	0.1250	133	0.3000	184	0.5250	235	0.8130
31	0.0101	83	0.1280	134	0.3040	185	0.5300	236	0.8220
32	0.0122	84	0.1310	135	0.3080	186	0.5350	237	0.8300
33	0.0148	85	0.1340	136	0.3110	187	0.5400	238	0.8380
34	0.0164	86	0.1370	137	0.3150	188	0.5440	239	0.8470
35	0.0177	87	0.1410	138	0.3180	189	0.5490	240	0.8560
36	0.0195	88	0.1440	139	0.3220	190	0.5540	241	0.8640
37	0.0216	89	0.1470	140	0.3260	191	0.5590	242	0.8730
38	0.0238	90	0.1500	141	0.3290	192	0.5640	243	0.8820
39	0.0260	91	0.1530	142	0.3330	193	0.5690	244	0.8910
40	0.0281	92	0.1570	143	0.3370	194	0.5740	245	0.9000
41	0.0299	93	0.1600	144	0.3410	195	0.5790	246	0.9090
42	0.0314	94	0.1630	145	0.3450	196	0.5840	247	0.9180
43	0.0327	95	0.1670	146	0.3480	197	0.5890	248	0.9270
44	0.0343	96	0.1700	147	0.3520	198	0.5940	249	0.9360
45	0.0363	97	0.1730	148	0.3560	199	0.5990	250	0.9450
46	0.0384	98	0.1770	149	0.3610	200	0.6040	251	0.9550
47	0.0407	99	0.1800	150	0.3650	201	0.6090	252	0.9640
48	0.0430	100	0.1830	151	0.3690	202	0.6130	253	0.9730
49	0.0453	101	0.1870	152	0.3730	203	0.6180	254	0.9830
50	0.0475	102	0.1900	153	0.3780	204	0.6230	255	0.9920
51	0.0497								

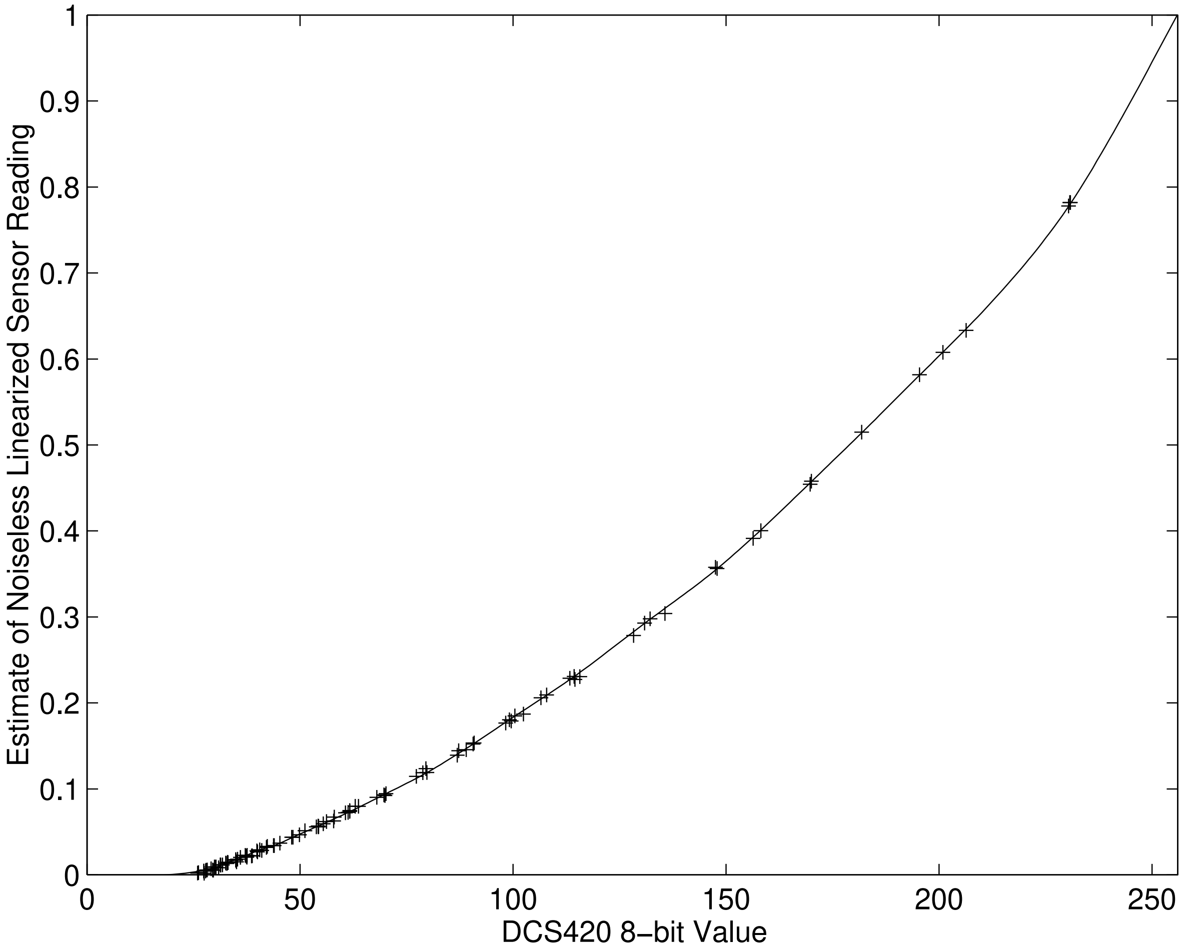

Figure 15: Calibration Curve - DCS-420.

6 Variation from Model

The data points vary slightly from the linear model for the DCS-200 and from the calibration curve for the DCS-420. In this section, we quantify the variation.

6.1 Kodak DCS-200

To estimate the slight variation from linearity of the DCS-200, we calculated the differences between values predicted by the straight line in the linearity plot of Figure 14 and actual values, for measured values above 20 and below 240. These differences are plotted in Figure 16. This calculation assigns zero difference to the maximum value in each data set and is thus only approximate. The error statistics reported below were calculated without using the maximum value in each data set. The mean absolute value of the variation is 1.13, and the mean value is 0.58. The average of the noise when estimated from the calibration curve is 12.5. This value is close to the value of 13.6 obtained by directly estimating the dark noise (see section 7.1.1 below). The root mean square value of the variation is 1.45. The maximum error is 4.67 and occurs for a green sensor reading.

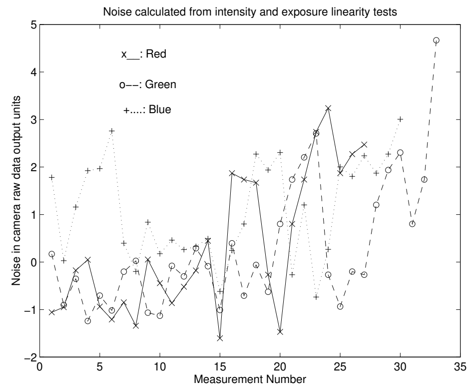

Figure 16: Variation from linearity for DCS-200.

6.2 Kodak DCS-420

To quantify the slight variation of the scaled data points from the curve in Figure 15, we calculated the difference between the data point and the value on the curve corresponding to the scaled intensity, i.e. the difference between indirectly measured values of $\mathcal{F}^{-1}(r) - n$ and values obtained from the calibration curve. As for the DCS-200, this calculation assigns zero difference to the maximum value in each data set and is thus only approximate. The error statistics reported below were calculated without using the maximum value in each data set.

The average absolute value of the variation was 0.0015. The root mean square value of the variation was 0.0021, approximately 0.5 units per 256 (for comparison with the variation for the DCS-200) and the maximum value was 0.0072, approximately 1.8 units per 256. As can be seen from the plots in Figure 17, the blue has most variation, and the red and green variations are comparable.

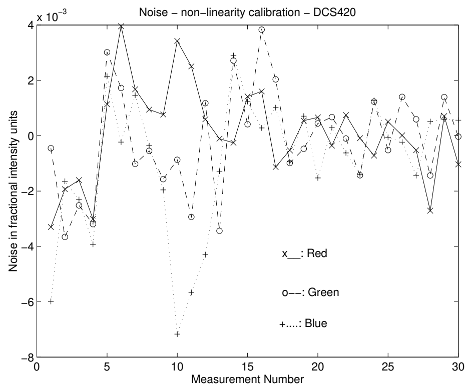

Figure 17: Variation from calibrated curve for the DCS-420.

7 Noise Measurements

We took a number of dark images at different times during our day-long experiments, and at different exposure durations. We first discuss the effect of exposure duration on dark current noise, and then the effect of aging.

7.1 Dark Current Noise

7.1.1 Kodak DCS-200

The dark noise was averaged over the same rectangular area of the center field as the linearity measurements. The data are tabulated in Table 2. Dark noise shows some variation with exposure duration, up to 4 units, but is quite constant over the different color bands. The mean of the data tabulated is 13.61, 13.63 and 13.61 for red, green, and blue sensors respectively. The overall mean is 13.62. The variances for the three sensor types are 0.78, 0.79 and 0.81 respectively; the corresponding standard deviations are 0.88, 0.89 and 0.90. The overall variance about 13.62 is 0.79 with a standard deviation of 0.89. Variation is greatest for blue sensors and least for red but the differences are slight.

The variation values may be compared to the values obtained from the variation from linearity calculations in section 6.1. The variation from linearity includes the dark noise variation, but is larger because it is not limited to the dark noise variation. It includes other non-linear aspects of the sensor response, including other noise sources like shot noise.

Figure 18 illustrates the fact that the variation of dark noise with exposure duration is not monotonic at low exposure durations, this could be because of inaccuracy in the mechanics of the shutter movement. At exposure durations of one-fourth of a second and higher the variation of dark noise with exposure duration is monotonically decreasing. This could be because the effects of dark current are averaged out at higher exposure durations.

Exposure time in seconds	Average Dark Noise Value in Camera Output Units		
	Red	Green	Blue
8	12.52	12.58	12.51
4	12.85	12.83	12.84
2	12.92	12.93	12.94
1	13.54	13.56	13.51
0.5	13.90	13.92	13.83
0.25	14.27	14.32	14.32
0.125	14.44	14.47	14.45
1/15	14.31	14.32	14.33
1/30	14.54	14.54	14.54
1/60	14.54	14.56	14.60
1/125	11.90	11.88	11.87

Table 2: Dark Noise vs. Exposure Duration, DCS 200.

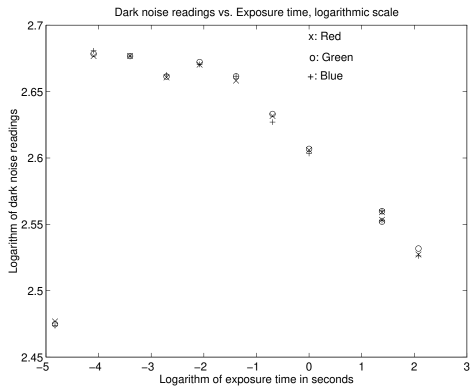

Figure 18: Dark noise vs. exposure duration - DCS-200 - logarithmic scale.

7.1.2 Kodak DCS-420

The average value of dark current noise is usually subtracted from readings that are known to be linear, i.e. readings predicted by equation (1). As the DCS-420 sensor outputs are the result of a non-linear function operating on the CCD measurements, (Equation 2), the dark noise average cannot simply be subtracted from the sensor readings. In fact, our calibration curve (Figure 15) provides an indirect estimate of $\mathcal{F}^{-1}(r) - n$ and the variability from this curve provides an estimate of the effective additive noise. None-the-less, obtaining a direct measure of the dark noise variability seems useful for an estimate of acceptable errors in RGB prediction for a companion report on camera calibration [2].

We took a few dark images (with the lens cap on) at various stages of the experiment, and at various exposure times. We calculated the average value over the same rectangle in the center field used for other measurements. The average value did not vary much, its average over the different images was 25.02, 25.01 and 25.06 over red, green and blue sensors respectively. Its overall mean was 25.03. Individual variances about individual means were 0.2375, 0.2207 and 0.2203 for red, green and blue respectively. Its overall variance with respect to the overall mean was 0.2266, and the standard deviation 0.4760.

If we convert the dark noise standard deviation to the linear domain (using the average slope of the calibration curve) we get a value of 0.0019. This is a little lower than the measured deviations of the data from the curve. As with the DCS-200, the difference is explained by the fact that variation from the calibration curve includes the effects of other types of noise besides dark noise.

7.2 Noise as a function of aging

The data of Table 2 were taken at the end of a day of experiments on the DCS-200, after 120 images were taken with the camera. The next morning, after just a few pictures, a few more dark noise images were taken. The average values of the dark noise images taken over the same rectangular area in the center-field of the camera are listed in Table 3.

The readings for 0.125 seconds are very close to but slightly below those taken earlier. The readings for 1/125 seconds, however, are above those taken earlier by more than 1 unit, an amount which is slightly higher than the standard deviation of the earlier set of readings. Even if this effect is real, it is small, and we suspect that treating the camera as a stationary device is satisfactory for most purposes.

Table 3: Dark Noise vs. Exposure Duration, DCS 200, Later Readings.

Exposure time in seconds	Average Dark Noise Value in Camera Output Units		
	Red	Green	Blue
0.125	14.05	14.04	14.02
1/125	13.08	13.15	13.08

8 Conclusions

We have investigated whether a linear response model describes the behavior of two CCD-based digital cameras. The Kodak DCS-200 is well-described by a linear response model, while the Kodak DCS-420 (when used with the 8-bit driver software) is not. It is possible, however, to use calibration data to correct the DCS-420 output to obtain linearized values.

More extensive checks of linearity would be possible. In particular, we did not directly test linearity with respect to superposition of light of different wavelengths. It would be surprising if such additivity failed, however, given that the intensity-response function is linear at each wavelength. In a companion report [2] we describe how we calibrated the spectral sensitivity of the DCS-200 and show that this calibration has good predictive power. The good predicitive power also serves as an indirect verification of additivity.

We also measured camera response variability and camera dark noise. These estimates of variability are important for sensor estimation (see companion report [2]), image restoration, and for assessing the precision required of a camera simulator.

References

[1] Lomheim, T. S. and Kalman, L. S., "Analytical Modeling and Digital Simulation of Scanning Charge-Coupled Device Imaging Systems" in *Electro-Optical Displays* ed. Karim, M. A., Marcel Dekker, 1992.

[2] Vora, P. L., Farrell, J. E., Tietz, J. D., Brainard, D. H., "Digital Color Cameras - 2 - Spectral Response", Hewlett-Packard Company Technical Report, March 1997.

[3] *Programmer's Reference Manual Models: DCS-200ci, DCS-200mi, DCS-200c, DCS-200m.* Eastman Kodak Company, December 1992.

[4] *MATLAB High-Performance Numeric Computation and Visualization Software, Reference Guide*, The MathWorks, Inc., 1992.

List of Tables

List of Figures