1 Testing the precision of an electronic camera's shutter

1.1 Constant aperture

We experiment with a commercial digital camera (a Canon 350D) in order to gain experience with the random error in exposure times that can be expected.

Our experiment consisted of taking 60 exposures at fixed aperture of a fixed target illuminated by a light source. From each image we extract the mean pixel count in a certain area corresponding to a flat evenly illuminated region. We obtained two sequences of images for two settings of the exposure time - 1/20th and 1/100th of a second, and used an aperture of f4.5. The camera ISO number was set to 400. It is not known whether the lamp used for illumination was constant or not.

Table 1 shows the results of the experiment. For the longer exposure time a smaller relative error was found. The relative error for different colors were not the same, although similar, hinting at some color dependency in the camera sensitivity. Generally, we see that at 50 msec we get relative errors in the 0.2-0.3% range when all images are used, or in the 0.1-0.2% range when images are handpicked in order to avoid those that show, e.g. an offset in the level from previous images (the camera clearly had some sort of sudden offset after images 0-10, and there was a gradual 'spin-up' problem for images 12-21) in the 50 msec sequence of images. For the 10 msec sequence of images a similar procedure was followed although there was mainly a 'spin-up' problem in this case, influencing images 0-15.

For the 10 msec sequence we find relative errors in the 0.4-1.4% range for all images and in the range 0.3-1.3% in the handpicked set.

We note that if the uncertainty in exposure level was entirely due to random scatter in exposure times, then the short exposure series should have a relative error proportionally larger than the short exposure series. This is not quite the case - the best results (column 7) scale by approximately 3.7. As we know nothing about the stability of the light source we used (a fluorescent overhead room light, left on for at least an hour before the experiments started), we do not see strong evidence that this particular camera does not have an exposure time uncertainty that is independent of exposure time (for 10 and 50 msec, at least).

In conclusion, we see that error levels in the 0.1-0.3% level exist for the Canon 350D shutter system - for short exposures in the 10-50 msec range, and when data are selected to avoid obvious problems..

1.2 Constant ratio of exposure time and aperture

We next performed a series of exposures allowing variation in the aperture as well as the exposure time, and extending the exposure times over a wider range. We chose pairs of exposure times and apertures that corresponded to a constant level of illumination of the detector. Table 2 shows the results.

Table 1: Results of a Canon 350D's exposure time repeatability. 60 images were taken at each exposure time, with f4.5. Columns labeled 1-8 represent the relative error in percent in the exposure time (as deduced from exposure levels in the image) for all 60 frames (columns 1-4) or in the best subset of frames (columns 5-8). Column 1 gives the relative error obtained from all three colors (R,G and B) while columns 2,3 and 4 give the relative error for the R, G and B images separately. Columns 5-8 are laid out similarly, but are for the 'best subset' of exposures which was determined by inspection.

Exposure time	1	2	3	4	5	6	7	8
50 msec	0.20	0.18	0.18	0.27	0.09	0.08	0.07	0.17
10 msec	0.50	0.48	0.35	1.39	0.44	0.49	0.26	1.29

Evidently the scatter is larger here, even for sequences with fixed aperture, than in the first test. For instance, the case of the exposure time 1/100s should match the 10 msec case in the first test, but doesn't - the scatter is about 3 times larger than before. The difference between the two runs were different aperture (4.5 vs 11), changes in the relative position of lamp and camera, and the time between exposures. In the first test there was 1 minute between each exposure, while 5 s only elapsed in the second series.

1.2.1 Fixed exposure time, fixed aperture but longer wait between exposures

The above observation prompted a test of whether letting the camera wait longer between exposures would lead to less scatter in the exposure levels. 30 images were taken at f11 and 1/100 s with a 1 minute pause between each exposure. For the full sequence of images a standard deviation of 0.94% was found. Excluding the 10 last images, which appeared to suffer trend-like increase in exposure level, resulted in a S.D. of 0.73%.

This result is not as good as in the first test above, but is a step in that direction, and we conclude that the camera seems to produce more stable exposure levels when a longer waiting period is introduced between exposures.

In case the scatter is a function of the aperture chosen, we perform yet one more series of 60 exposures, using f4.5 adn 1/100 s. The standard deviation turns out to be 0.94% if all 60 exposures are used. As there is a marked jump in the level of the images after the 25th image we calculate the standard deviation for the images following this jump, and we get 0.42% which is very much in line with the first test results.

We conclude that, apart from unexplained offsets in the exposure levels, it is possible to have a standard deviation in the flux level at f4.5 and 1/100 s that is as low as 0.4%.

Table 2: Results of a Canon 350D's exposure time and shutter aperture repeatability. 10 images at each pair of exposure-time/f# were obtained. The mean of all exposures was 99.88 and the standard deviation 2.47% of the mean. Mean values were taken of R,G and B pixels in each frame in a flat evenly illuminated area.

Exposure time seconds	f#	mean	S.D. % of mean
1/800	4	99.15	3.49
1/400	5.6	99.11	3.27
1/200	8	98.32	1.82
1/100	11	100.44	1.32
1/50	16	100.49	1.62
1/25	22	100.38	2.24

1.3 Linearity

The detector is assumed to be linear - that is, the pixel counts increase proportional to exposure time. We test this on the Canon EOS350D by exposing a flat evenly illuminated surface from 1/8th of a second insteps to 1/125th seconds. This will test whether the detector+shutter+aperture control is linear.

Our first attempt, using the `JPEG` file format failed - the pixel counts did not increase linearly with exposure time. This must be because the `JPEG` format destroys information in the image while packaging the data into a file. Not only is there compression, it would appear there is also some sort of transformation.

We therefore repeated the trial and saved data in the `RAW` format (on Canon DSLRs called `CR2`). This format cannot be read in `IDL` so we transformed the images into 12-bit `TIFF` format using the `convert` programme in `ImageMagick`, under `DOS`. The `TIFF` files were then read in `IDL` and analyzed. The pixel average in a box on the image was calculated in each image and then all mean values were plotted and the standard deviation of the values calculated. The scatter in mean pixel count divided by exposure time was 3.19%. Figure 1 shows the results. There is no indication of non-linearity but there is scatter.

Only one exposure at each exposure time was obtained - mainly because the work required in transforming `CR2` files into `TIFF` files is considerable! As the resulting `TIFF` files do not appear to have any `EXIF` information the shutter speed has to be entered manually. A repeated test with more images taken at each exposure setting might produce more stable results.

Figure 1: Testing the canon ESO350Ds linearity by exposing the same target at different exposure times (at fixed aperture f5.6). Plotted are (lower panel) mean pixel value in a square area of the image against exposure time, and (upper panel) the ratio of mean pixel value and exposure time against exposure time.