smear

When an interline-transfer-CCD image sensor is read out, the generated charge carriers are transferred from the light sensitive part (photodiode) of a pixel to the shift register. This is located next to the photodiodes and acts like a potential bucket. As there is weak light sensitivity on these shift registers, they are shaded to prevent the additional generation of charge carriers. When the charge transfer to the shift registers is complete, they are vertically shifted, row-by-row, to the horizontal readout line, which is then read out serially. This row-by-row vertical shifting is comparable to an endless conveyor belt. With every shift step, all registers are shifted by one register location, including those register rows that were previously drained from the image.

1 smear

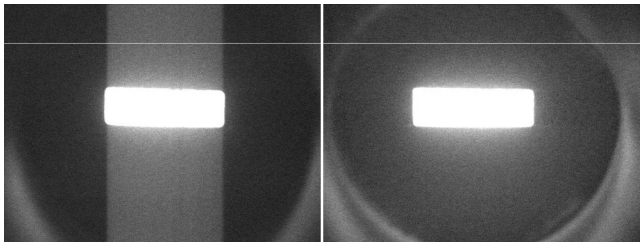

Figure 1
The left image shows a back illuminated rectangular aperture with an exposure time of 1 ms in a stretched scaling (48-100 counts correspond to 0-255 gray levels). The white line illustrates the position of the row of pixels which has been extracted to be shown in figure 2. The right image shows the same aperture, with the same scaling, at 100 ms exposure time and reduced back illumination. Both images have similar intensity values. To achieve the same gray level, the intensity of the light had to be 100x higher and caused 100x more smear. The circular structure visible within the outer regions of the images is caused by reflections within the set-up.

If an intense light source is imaged onto the CCD image sensor, this can generate unwanted charge carriers in the shielded shift registers (mainly due to the scattering of light on the CCD chip) in every line or row that is shifted below the spot. This results in additional unwanted light signals called “smear”. Smear can be recognized as bright vertical bands below and/or above the bright image spot (interline or frame transfer architecture). Smear is dependent on the light intensity (therefore short exposure time, high intensity, more smear - long exposure time, low intensity, less smear), image sensor readout time or speed (slow readout, more time for smear - fast readout, less time for smear) and the corresponding structure of the image sensor (quality and presence of microlenses influence the light scattering properties and therefore smear). In general, it is a characteristic of the integrated image sensor.

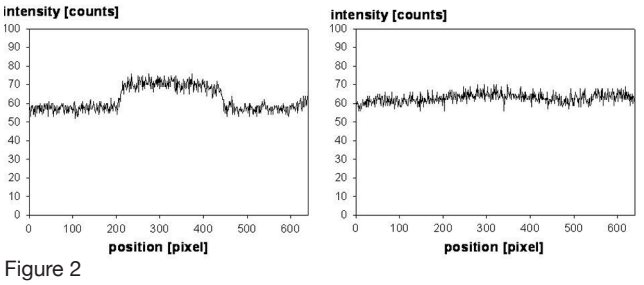

Figure 2
The graphs show the read out profiles of both aperture images in figure 1. The left graph clearly shows the step-like signal increases due to smear (smear approximately equal to 10-12 counts), while the dark value is similar for both images (58-62 counts).

Figure 3
These two images of the aperture from figure 1 are displayed using a different scaling (0-255 gray levels correspond to 0-2500 counts). The left image was taken with an exposure time of 1 ms, while the right image was exposed for 100 ms with reduced illumination. The white line shows the position of the readout profile in figure 2.

2 smear reduction / prevention

2.1 reduction of light signal

If the strong light signal is reduced or removed, smear will be reduced or removed too - a the trivial solution.

2.2 extension of exposure time

The main relationship of interest for smear estimation is the relation of light intensity vs. image sensor readout time. The latter can only be changed by change of pixelclock and if available two ADC readout instead of one ADC readout. The former can always be adjusted by the user (e.g. exposure time control).
To illustrate this relationship, the following two sample images, which have been recorded with the same camera, are displayed. When the illumination is constant, smear can be reduced by increasing the readout speed and therefore decreasing the image

smear

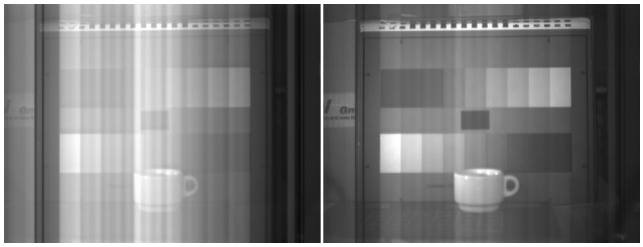

Figure 4
The two images illustrate the effect on smear, when the exposure time is constant and the image sensor readout time is changed. Left image: exposure time of 50 µs, one ADC readout at 10 MHz, right image: same exposure time, two ADC readout at 2 x 40 MHz.

sensors readout time. Another option is the decrease of the illumination (e.g. closing of aperture) and subsequent increase of the exposure time.

2.2 turn light off during image readout

The light signal can be masked or turned off after the exposure is finished. This way, no light will hit the sensor before and after exposure, while the image is read out. The images in figure 5 illustrate this.

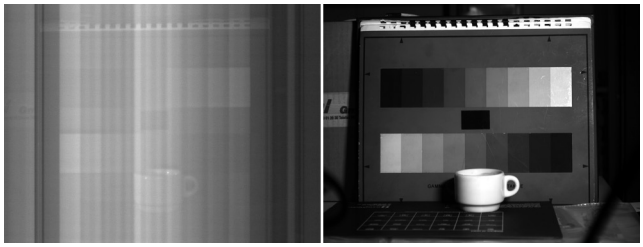

Figure 5
The two images illustrate the effect on smear, when light is excluded during image sensor read out. Left image: exposure time = 5 µs, with continuous illumination of the scene, right image: same exposure time, illuminated with a flash light.

That is also the reason why manufacturers of modern digital photo cameras still integrate mechanical shutters. By this the images can be read out without any additional light disturbing the readout process. However, since many of these cameras use the continous display of live images instead of a view finder, whenever there is a strong light source present in the displayed scene, immediately the vertical stripes of smear become visible, if a CCD is used as image sensor. These stripes are gone if the image is taken, because then the shutter is closed during readout, which is no option for continuous display, since the shutter is too slow.

3 smear in frame transfer CCD image sensors

The previous explanation applies only to smear in interline-transfer CCD image sensors, which are suited for high speed applications as opposed to frame- transfer CCD image sensors (typ. time for one frame-transfer is at minimum 1 ms). Smear also exists in frame-transfer CCD image sensors, but is not symmetrical. In frame-transfer CCD image sensors, the light sensitive cells are shift registers themselves. Within the frame-transfer process, the entire image is transferred in total (frame transfer). Technically, this

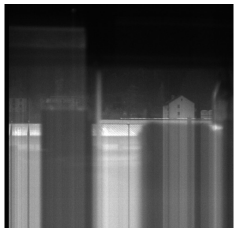

Figure 6
frame transfer CCD image sensor with smear

means a fast clocked row-by-row shifting into the shielded storage area. In contrast to the interline-transfer process, the image is shifted just below the bright image spot for the readout process, which does not influence the first readout rows. Measures against smear are similar to those described herein.

4 smear in CMOS image sensors

In CMOS image sensors, each pixel is adressed and read out directly, preventing any shift below the bright image spots. The direct readout prevents the generation of smear in CMOS image sensors.

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