warm / hot pixel

The technical term “warm/hot pixel” describes a phenomenon of digital image sensors that can easily be observed when long exposure times are taken (generally > 3s, although this can vary from chip to chip). When images are recorded using long exposure times, single pixels are observed that appear to be much brighter than surrounding pixels. When dark images (no optical input) are recorded using long exposure times, bright pixels are observed at the same locations. These bright pixels are referred to as warm or hot pixels. The term “warm pixels” is generally used to refer to pixels that follow the impinging light, while “hot pixels” refer to pixels don’t follow the impinging light. In either case such hot/warm pixels are typically much different than neighborhood pixels.
Physically, these “warm/hot pixels” are mainly caused by charge leakages within the image sensor chip. Although the warm/hot pixels are randomly distributed within the chip, they are in a fixed position. Under normal conditions (shorter exposure times, normal light), many of them are not visible since their contribution to the general noise level is below this level.

1 hot pixel images

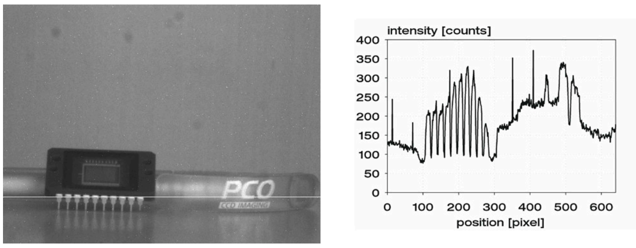


Figure 1
image (VGA, exposure time 10s)

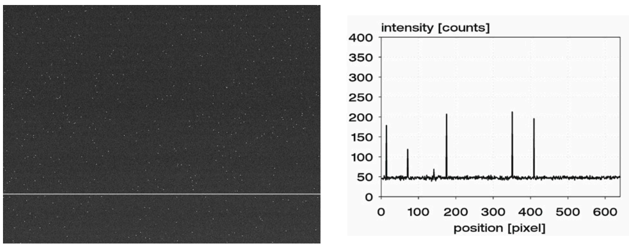


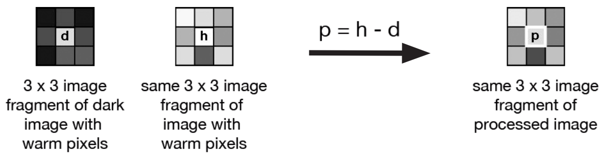
Figure 2
dark image (VGA, exposure time 10s)

The images shown here (fig.1 and 2) were recorded with a CCD camera using the following parameters: VGA (640x480 pixels) resolution, exposure time of 10s. The photos are scaled to a maximum of 400 counts (0-255 gray levels => 0-400 counts). The white line in each image indicates the extracted profile which are graphically displayed to the right of each image.
“Warm/hot pixels” become larger than the general CCD noise only during long exposure and in low light conditions. Since they are an inherent part of CCD chips and cannot be prevented from occurring, image processing considerations have to be taken when long exposure times are required.

2 image processing to remove warm / hot pixels

2.1 dark image subtraction

The recording of a dark image with the same exposure time as the image to be measured is one option. This dark image is later subtracted from the measured image. This process, called dark field correction in astronomy applications, requires the recording of a dark image for each exposure time. As a consequence, the general level is shifted downward (see fig. 3, the same scaling was used as for the other images and it appears to be darker). In dark areas of the image, negative values might occur, but the correction itself is a fast calculation.



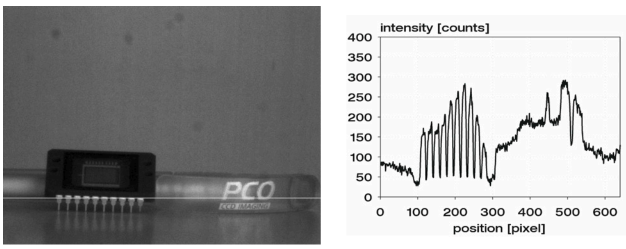


Figure 3
The image above is the result of a dark image subtraction of the measured image (fig. 2). The graph shows the extracted profile from the line position in the image. The imaging and display conditions are given in figures 1 and 2.

2.2 median filter

Median filtering is commonly used to remove the “salt & pepper” noise in images, which is similar to warm/ hot pixels. The “salt & pepper” noise features noise amplitudes in both directions (black & white), while

warm / hot pixel

the warm/hot pixels have larger than average values. Median filtering is also known as a "neighborhood operation", since each pixel in the processed image is the result of the evaluation of a defined neighborhood area in the original noisy image, as shown below. The original pixel "h" is replaced by a processed pixel "p" by looking at the pixels n1 through n4 plus "h", and selecting an intensity value that is closest to their average. Each pixel must be calculated individually over the whole image, which is more time consuming. As a consequence the processed image is smoothed such as when calculating averages or boxcar smoothing where edges, which are in the image are in the size of the area that is used for the evaluation, are broadened. Median filtering does not require dark images to be recorded. This is at the expense of spatial resolution, considering it is a smoothing process."

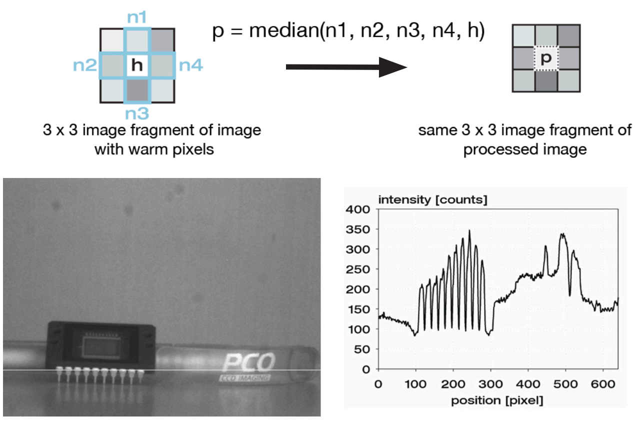


Figure 4
The image above is the result of a Median filtering of the measured image (first page). The graph shows the extracted profile from the line position in the image. The imaging and display conditions are given in figure 1 and 2.

2.3 pixel list & neighborhood averaging

Taking a dark image with a long exposure time allows the mean and standard deviation of the dark image to be calculated. In this case, "long" is defined as a time at least equal to or greater than the exposure time of the image to be measured. Defining an appropriate level determines which pixel is assumed to be a warm or hot pixel (e.g. every pixel that is larger than [mean + 2 * standard deviation]). For a given dark image, a warm or hot pixel list can be created, outlining the pixels' positions in the dark image. The measured image can now be corrected by replacing the hot pixel by the average value of its four neighbor pixels (if any neighbor is also a hot pixel, which has low probability, it is replaced by the average value of the remaining non-hot pixel neighbor). The warm or hot pixel list of the dark image, recorded at the longest necessary exposure time, only has to be recorded once and can be used for all further measured images in the long exposure range. This process, a relatively fast calculation, results in minimal blurring, because of the small amount of warm or hot pixels that have to be calculated.

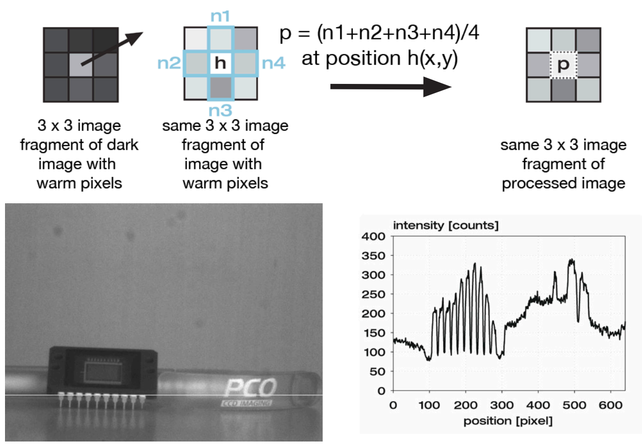


Figure 3
The image above is the result of creating a warm/hot pixel list derived from the dark image (first page) and replacing it by neighborhood averaging. The graph shows the profile extracted from the line position in the image. The imaging and display conditions are given in figure 1 and 2.

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