Pixel Size & Sensitivity

Larger Pixel Image Sensors Are Not Always More Sensitive

The number of pixels in image sensors is of central importance for the image quality. There is a general tendency towards higher resolutions, because they are associated with higher information content. Higher resolutions mean smaller pixels. The sensitivity of the pixels is another important feature (characteristic) of an image sensor. Larger pixel image sensors are said to be more sensitive than smaller pixel sensors. This article explores the relationship between the pixel size of an image sensor and its sensitivity.

Pixel Size - Fill Factor

The fill factor of a pixel describes the ratio of light sensitive area versus total area of a pixel, since a part of the area of an image sensor pixel is always used for transistors, electrodes or registers, which belong to the architecture or readout technology of the pixel of the corresponding image sensor (CCD, CMOS, sCMOS). Only the light sensitive part might contribute to the light signal which the pixel detects.

In case the fill factor is too small, this fill factor usually is improved by the addition of micro lenses, where the lens collects the light impinging onto the pixel and focuses the light to the light sensitive area of the pixel.

Pixel Size - Comparison Total Area / Resolution

If the influence of the pixel size on the sensitivity, dynamic, image quality of a camera is to be investigated, there are various parameters that can be changed or kept constant. In the following different experiments are suggested to answer the question.

Experiment 1: Larger Pixels, Low Resolution

In the first experiment square shaped image sensors are assumed, which fit into the image circle or imaging area of a lens. For comparison a homogeneous illumination is assumed therefore the irradiance is constant over the area of the image circle. The left image sensor (fig. 1a, sensor A) has smaller pixels but higher resolution,
while the right image sensor (fig. 1a, sensor B) has less and larger pixels. Each pixel of camera B is four times as large as a sensor A pixel.

For the considerations it is also assumed that both image sensors have the same fill factor of their pixels, which means that the ratio of light sensitive area versus total area of a pixel is the same.

Under these circumstances a pixel of camera B is able to collect four times as many photons as camera A. However, this is only one of the aspects which influence the image quality. The comparison neglects resolution and signal-to-noise ratio (SNR). The SNR gives information on the quality of the picture signal, which consists of the usable or information signal and the noise signal. A higher SNR usually means a better image quality.

Figure 1b assumes three image sensors with the same total area, which fit into the image circle of a lens, but with different resolution. This comparison shows: the larger the pixels the worse the resolution and information content of the image. As can be seen in figure 1b, image I shows the nicest image but has the worst SNR per pixel, in image II the SNR / pixel is better but due to the smaller resolution the image quality is worse compared to I. Finally image III with a super large single pixel shows the maximum SNR per pixel but unfortunately the image content is lost.

To return to figure 1a: To compare the image quality the information content should stay the same. That's why we summarize four pixels of camera A into one large pixel in order to regard the SNR. The result of the comparison: With a high light intensity the four smaller pixels have the same value as one large pixel. With low light intensity the four smaller pixels show the better SNR under certain circumstances, because smaller pixels often have a lower random noise. So regarding SNR image sensors with larger pixels are not always better.

**Experiment 2: Constant Resolution**
In the second experiment the image sensor of camera A has small pixels, while the camera B image sensor has larger pixels. In contrast to experiment 1 resolution and information content are the same in both cameras. The number of pixels should be the same at the same object distance (fig. 2). To achieve that condition it is necessary to change the focal length of the lens in front of the image sensor with the small pixels: The information, which before has been spread to a larger image area, now has to be concentrated to a smaller area.

To answer the question which sensor has the brighter signal and which sensor has the better SNR, we look at the same number of pixels but with different size this time, but due to the different lens at the same aperture the irradiance for the smaller pixels is higher. The comparison shows that the larger pixels have a higher readout noise than the smaller. Accordingly they have the worse SNR with low light intensity. So this comparison shows again that the assumption that larger pixels are more sensitive than smaller ones is not supported by facts.

However, larger pixels have other benefits, such as a higher fullwell capacity. The fullwell capacity of a pixel of an image sensor is one important parameter, which determines the general dynamic of the image sensor and therefore also for the camera system. Although this fullwell capacity is influenced by various parameters like pixel architecture, layer structure and well depth, there is a general correspondence also to the light sensitive area. This is also true for the electrical capacity of the pixel and the dark current, which is thermally generated. Both, dark current and capacity add to the noise behavior, and therefore larger pixels also show larger readout noise. With bad lighting conditions, this can be a disadvantage for the signal-to-noise ratio.

**Conclusions**

The user should choose his camera with respect to pixel size and sensitivity according to his priority objective: Is it important to image a large image section? Or are many details and a high resolution most important? How high is the light intensity? The answers to these questions determine the ideal pixel size. For short exposure times and bad lighting conditions the sensitivity is important. In this case the user should decide for small pixels. If the user desires a high contrast, large pixels are to be preferred. Pixels of medium size have their benefits, too: In the size between 6 and 8 µm (pixel pitch) the relation between noise behavior, fullwell capacity and dynamics is ideal.

Generally it is a good idea to compare cameras with respect to pixel size and sensitivity. To do this, the user should image the same scene to each camera, while he keeps the object distance and the illumination constant and keeps or adjusts the same resolution for all cameras. Then he should select a proper focal length for
each camera, whereas each camera should see the same image on the active image sensor area. Under these circumstances the user can compare the sensitivity - and choose the best pixel size according to his goals.

Authors
Dr. Gerhard Holst (corresponding author)
PCO AG
Kelheim, Germany

Dr. Mona Clerico
Storymaker GmbH
Tübingen, Germany

Contact
PCO AG
Donaupark 11
93309 Kelheim
Phone: +49/(0)9441/2005-50
Telefax: +49/(0)9441/2005-20