Are More Pixels Better?

The most frequently asked question when buying a new digital security camera is, "What resolution does the camera provide?" The resolution is indeed an important factor in obtaining high-quality images, but it's only the start. You won't get the most out of your camera choice unless you factor in some other characteristics of the image sensor, as well as optics, mechanics, and other features. Higher resolution may not be the best choice for the specific application you have in mind.

Read on for a quick tutorial on some of the factors that influence image quality, beyond simply resolution. We'll discuss important sensor parameters such as sensitivity, full well capacity and dynamic range, and give you some insight into optical and other issues created by higher resolutions. With this information you can make the best choice for your needs and get the best value for your money.

Resolution – Does it Really Matter?

Even though many image-processing applications could run perfectly well with VGA resolution, other applications have moved up to using cameras with anywhere from 1 to 10 megapixels, as permitted by the desired frame rate. For many users higher resolution is very desirable. Currently, cameras with 5 megapixels are becoming the new standard, and some camera manufacturers even offer models with 10 megapixels or more.

The number of pixels available on a camera continues to increase, especially for consumer cameras. A few years ago,1 to 3 megapixels was common. Now, we often see 10 to 16 megapixels, or more. Improvements in layout, and cost factors relating to the silicon, have contributed to increased resolution. This cost advantage is finding its way into the network camera marketplace as well. Consider that a typical 1/3" sensor with 5 megapixels has a pixel size of just ~2 µm (for a color sensor, due to the interpolation, the effective pixel size is twice as large in length – or four times the area). By comparison, a VGA sensor of the same area has a pixel size of 7.4 µm.

But having smaller pixel sizes does have some disadvantages, or at least some considerations that must be taken into account. The main consequences of smaller pixels are:

- Higher demand on lens optics
- Smaller (shallower) depth of field, and the need for more precise adjustment
- Reduced low light sensitivity
- Combined with a higher number of pixels higher data rate and reduced frame rate

Optical Limitations – Don't Use a Low Quality Lens for High Quality Imaging.

Moving on to the lens that projects the object onto the sensor's plane – how does it interact with pixel size? Consider a very tiny spot on the object to be photographed. The typical camera "lens" is actually a system of several lenses through which the light must travel. This lens system will correct for numerous deviations that a single lens would have. Good lenses can transmit a spot size of five to seven microns, and very good lenses might achieve even less than five microns. Cheap lenses might have a spot size up to 15 or 20 microns. Smaller spot size means high quality optics.

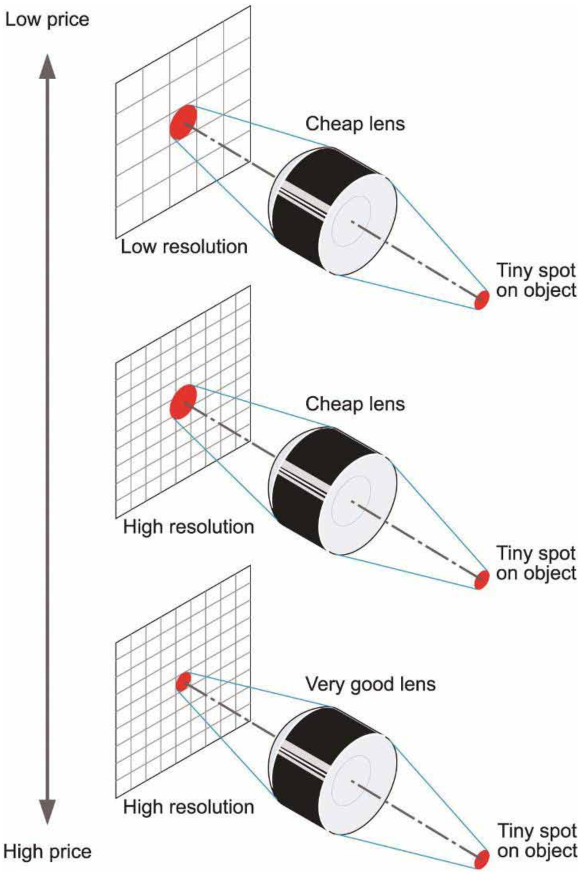

Fig. 1: A cheap lens can generate sharp images on a low-resolution sensor (upper image). But with the same lens, a high-resolution sensor will yield blurred images (middle image). A high-resolution sensor's full potential can only be reached by using a high quality lens (lower image)

But even if the corrections produced by the lens "system" were perfect, there is a physical limitation on lens performance, known as the diffraction limit. No lens on earth can image a point to less than a single point in the image plane; the smaller the aperture of the lens, the larger the diameter of this single point. The lens' F-number, expressed in microns, gives you the diffraction limit in the sensor plane for that lens. For example, a lens with an F-number of 5.6 will have a spot size of about 6 microns on the sensor as the best it can achieve.

$\text{DiameterAiry} = 2.44 * k * \lambda$
(with λ = wavelength and k = F-number = f/d,
with f = focal length, d = diameter of iris)

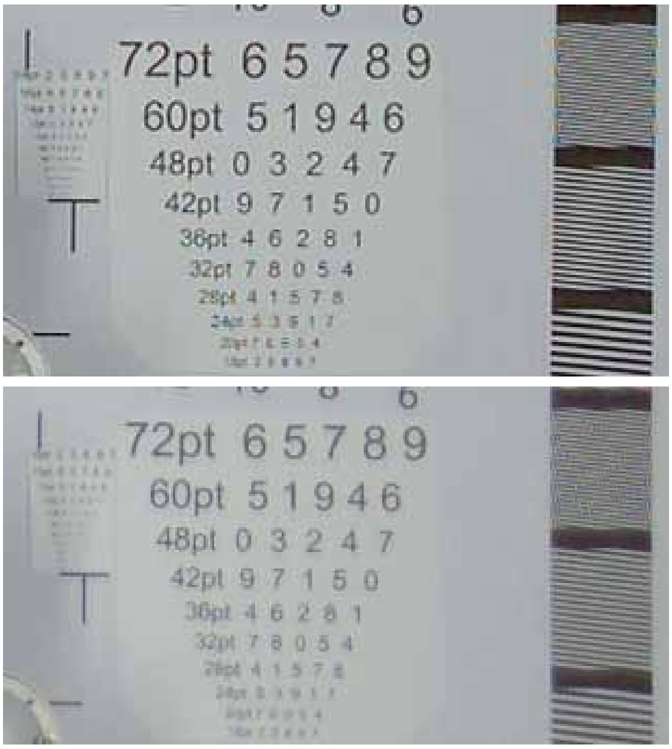

Fig. 2: Comparison between a high-quality lens (upper image) and a lower quality lens (lower image); the lower image exhibits less contrast and lower resolution and color fidelity than the upper image.

Depth of Focus (DOF)

We have seen how smaller pixel size must be matched with the right lens optics. But smaller pixel size also imposes tighter tolerances for the mechanical alignment, for the flange and the mechanical interface, as well as tolerances for sensor positioning for all six degrees of freedom (x, y, z, tip, tilt, and rotation).

But not only the manufacturer is involved in these challenges. Also the user of the camera has to pay more attention to the adjustment of the focus.

The tolerances become even tighter if a large lens aperture is chosen.

To summarize, smaller pixels must be matched by other features in the camera, for best performance. Also remember that color cameras using a Bayer pattern filter (red, green, red, green, etc. for odd lines, and green, blue, green, blue, etc. for even lines) double the effective pixel size, because they require a 2 x 2 pixel array to capture full red, green, and blue (RGB) information.

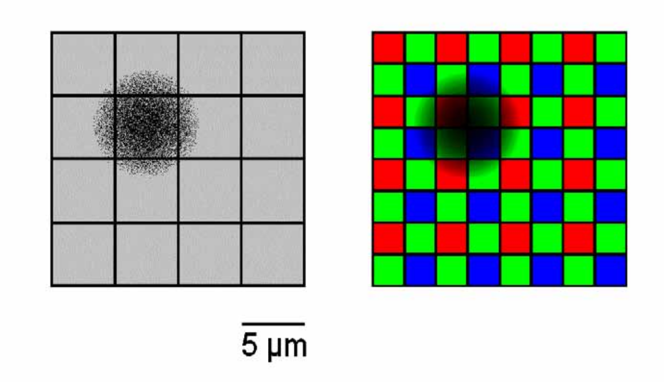

Fig. 3: Comparison between pixel size in a monochrome sensor and effective pixel size made up of a Bayer pattern in a color sensor

Sensitivity and Dynamic Range

Beyond pixel number and size, lens quality and alignment tolerances, additional camera parameters to consider are the dark noise, the sensitivity, the saturation capacity, and the related dynamic range. Let us first consider the term dark noise, since this is the basis for the understanding of the other parameters.

All cameras have dark noise that delivers an output signal noise even in total darkness hence the reference "dark noise". We measure and compare the signal-to-noise (S/N) ratio in decibels (dB). The higher the dB rating, the less apparent the dark noise artefacts will be. The dark noise has the largest effect on the S/N ratio when only a small amount of light is available. This happens when the video signal created under low light conditions is smaller than the dark noise signal. The more light that is in the scene, the lower the effect of dark noise.

Dark noise is stated as a standard deviation of the number of electrons. When the signal from a pixel caused by photons (i.e. by light), is at the same level as the pixel's dark noise, this is called the detection limit, which tells you the camera's sensitivity threshold. With less light than the threshold, you do not receive any image information. The more pixels you have (on a sensor of a given size), the more photons are required to ensure that the number of photons arriving at each pixel will reach the sensitivity threshold. This means that to reach the same signal-to-noise ratio, a 5-megapixel sensor requires four times as many photons as a 1.3-megapixel sensor, and 16 times as many photons as a VGA sensor. Modern sensors sometimes use backside illumination for higher efficiency, to mitigate this difference a little bit.

To obtain a reasonable image quality, the detection limit must be exceeded. A minimum signal-to-noise ratio of at least 5 or 10 is necessary (this minimum light value is defined at Basler as a signal-to-noise ratio of ~6 or ~15 dB).

Fig. 4: Sample images with high noise (right) and low noise (left). Under low light conditions, images from sensors with small pixels may exhibit more noise than those with large pixels.

This explains the sensor's limits with respect to low light levels. But where is the limit of a sensor with respect to a very large amount of light? This question is answered by another term: the full well capacity or the saturation capacity. The full well capacity represents the maximum number of electrons that an individual pixel can hold. This corresponds to the upper limit of the sensor output at high illumination levels. On CCD sensors, this number is often artificially limited to a reduced saturation capacity, to avoid other image artifacts such as over exposure and blooming.

Now that we have defined the lower and upper limits of the sensor response to overall light, we can finally explain the missing term "dynamic range": it is defined by the ratio of the saturation capacity (full well capacity) to the sensitivity threshold. In other words: the dynamic range is the ratio of the brightest and the darkest values that a pixel is able to detect.

Good CCD cameras without Peltier cooling will have about 7 to 10 electrons of dark noise, but even 20 electrons is still an acceptable standard. For a good camera with a 20000 electrons saturation capacity and 8 electrons of dark noise, the dynamic range covers a factor of 2500, which corresponds to 68 dB or 11.3 bits (1 bit = 6.02 dB).

Data Compression and Frame Rate

High resolutions and high frame rates create high bandwidth and storage demands.

In IP applications, compressed data formats are widely used, reducing the data rate in order to use standard internet protocols. But even with compressed data, high resolution sensors produce other challenges that must be addressed. The user must decide whether higher resolution is really important when it comes to pricing the network layout and the hardware for the video management system.

The effect of image resolution on the frame rate must be considered as well. A higher number of pixels causes a larger amount of data to be handled inside and outside of the camera, and reduces the available frame rate. The higher the resolution, the lower the maximum frame rate potential, and vice versa. For some applications it is possible that the user must compromise between frame rate and resolution.

Summary of Considerations

What considerations must be made when choosing the right camera for your application? It depends on a number of factors. Do you require a general overview of a scene or the ability to read finer details, such as license plates, facial recognition or playing cards? Answering these questions will determine what resolution is required to meet your needs. Make sure you don't waste the extra money you have spent on a high resolution camera by saving money on a lower quality, cheap lens. The lens is the most important factor in the imaging chain where high resolution (megapixel or multi-megapixel) is required. The lens choice becomes more crucial as pixels becomes smaller (resolution gets higher). Under difficult light conditions, the camera has to provide a good signal-to-noise-ratio to ensure image quality. So first review the S/N ratio on the cameras specification sheet (60 dB or better) and then select a lens with the largest aperture (lowest f-stop) available to collect as much light as possible. It may be necessary to add additional or increase available light under extreme conditions.

Author

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About Basler

Basler is a leading global manufacturer of digital cameras for industrial and video surveillance applications, medical devices, and traffic systems. Product designs are driven by industry requirements and offer easy integration, compact size, excellent image quality, and a very strong price/performance ratio. Founded in 1988, Basler has more than 20 years of experience in vision technologies and has designed and manufactured high quality digital cameras for almost 15 years. The company employs around 300 people at its headquarters in Ahrensburg, Germany, as well as in international subsidiaries and offices in the U.S., Singapore, Taiwan, and Korea.

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