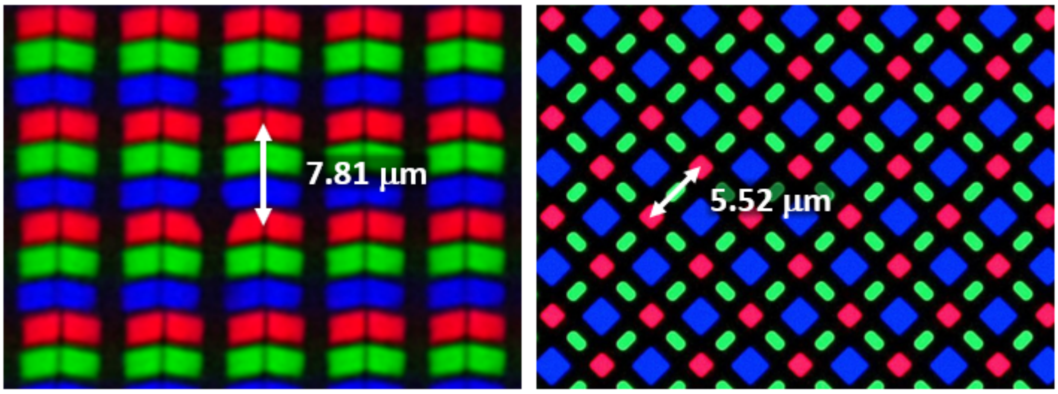
Scuola di Microscopia

Pixel Pitch

Spartaco Santi – *January 2026*

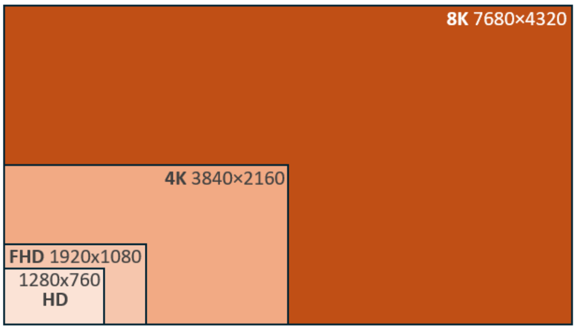
Display

Pixel pitch is a measurement that indicates the distance between individual pixels on a screen, typically in digital displays such as monitors, televisions, or LED screens. It is expressed in millimeters or microns and represents the horizontal and vertical distance between the centers of two adjacent pixels. The smaller the pixel pitch, the closer the pixels are to each other, which usually results in a sharper and more detailed image. This parameter is especially important for high-resolution displays or when high-quality viewing is desired, such as in television broadcasting, advertising, or large-format screens.



Layout of an OLED screen showing the sub-pixels of an iPhone 7 (on the left) and an iPhone 14 Pro Max (on the right). In the latter case, the red, green, and blue sub-pixels differ significantly in size: the blue sub-pixel is by far the largest because it has the lowest luminous emission efficiency.

Therefore, it is intuitive to think that a display with a smaller pixel pitch allows for higher resolution. However, this could lead to increased system costs and reduced brightness due to the smaller size of individual elements. Variables to consider in this context include viewing distance and screen size, to prevent the human eye from perceiving individual pixels. For example, to determine the optimal viewing distance for a Full HD screen (1920x1080 pixels), it is advisable to multiply the screen size by 1.7. So, for a 65-inch TV (165 cm diagonal), the ideal viewing distance would be about 2.8 meters. With an Ultra HD or 4K screen (3840x2160 pixels), which has four times the pixel density, the optimal distance is halved, allowing comfortable viewing even at 0.85 times the diagonal—about 1.4 meters in the case of a 4K television.

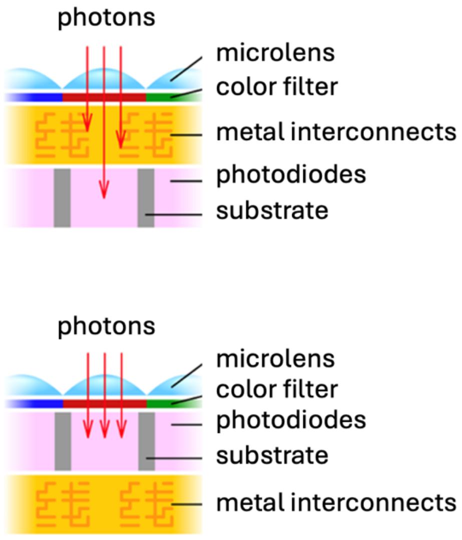


Screen Resolution: HD, Full HD, Ultra HD (or 4K), 8K

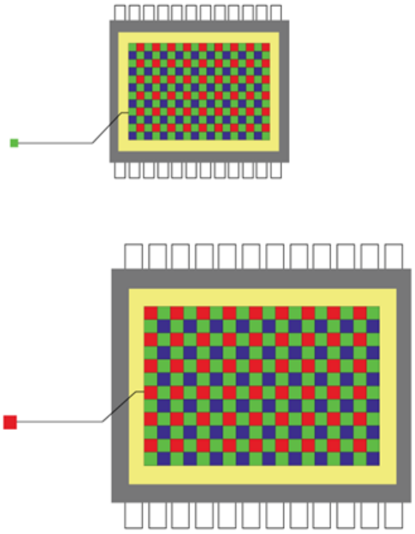
These calculations are based on an approximation of the human eye's resolving power, which in linear terms is about 0.1 mm (resolving 10 lines per millimeter, or approximately 250 dpi at a viewing distance of 20–30 cm). However, if we consider the total field of view of the human eye (about 180° horizontally and 120° vertically), the number of pixels that could theoretically fit within that field would be equivalent to around 500 megapixels. Of course, this is a rough estimate that assumes the same angular resolution across the entire field of vision, which is not the case in reality—since the eye's sharpest vision is concentrated in the fovea, while peripheral vision has much lower resolution.

Sensor

Even in a camera sensor, pixel pitch refers to the distance between the centers of two adjacent pixels. And once again, the smaller the pixel pitch, the higher the sensor's resolution. Cameras with smaller pixel pitch generally have more pixels packed into the same area, resulting in higher-resolution images. However, this also means that each pixel is physically smaller and may be less sensitive to light, which can lead to a lower signal-to-noise ratio, a key measure of image quality. A sensor pixel can be imagined as a bucket for collecting light: the larger the pixel, the more light it can capture. This is one of the major differences between the small sensors found in smartphones and the larger ones used in dedicated cameras. As a result, the more light each individual pixel can gather, the greater the dynamic range of the sensor, meaning it can capture more detail in both shadows and highlights. Manufacturers continuously work to improve the efficiency and performance of smaller pixels through technologies such as backside illumination (BSI), which improves light-gathering by rearranging the sensor's structure, and advanced noise-reduction algorithms to compensate for the challenges of smaller pixel sizes.

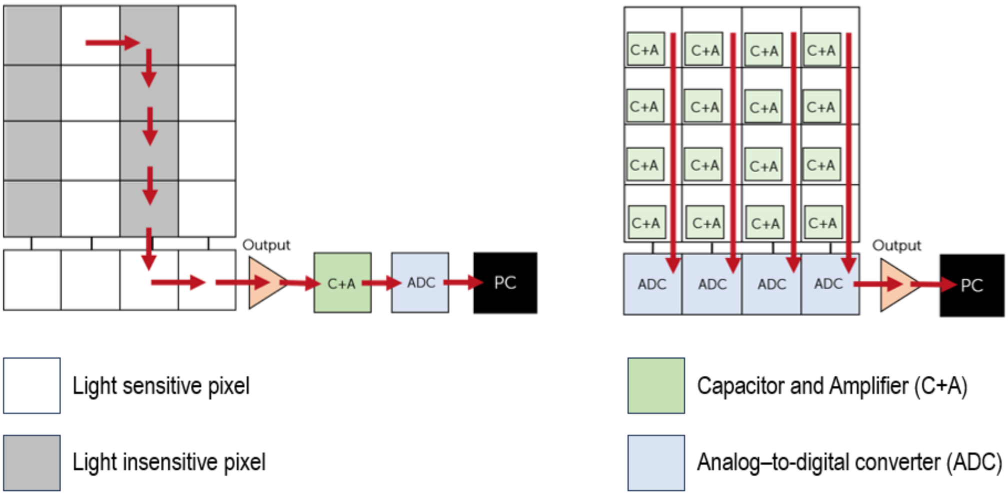


Front-illuminated sensor (top). The electrode grid structure is positioned above the sensor's photosensitive area. It typically has an efficiency of 60–80%.
Backside-illuminated (BSI) sensor (bottom). The electrical structures are located beneath the photosensitive region. Quantum efficiency can reach up to 95%.



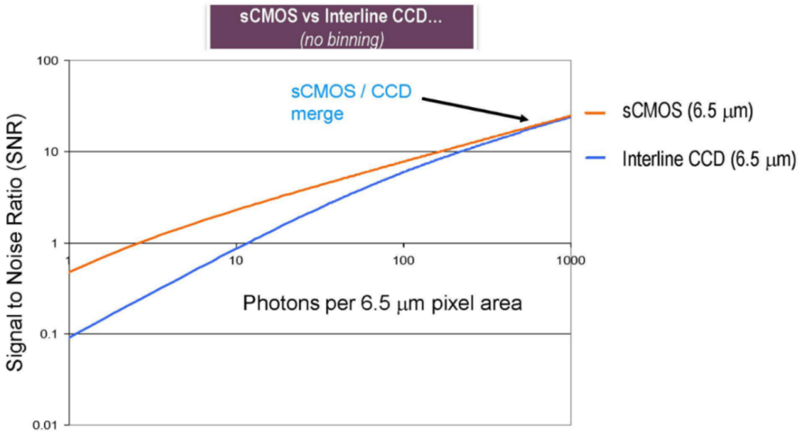
With the same number of pixels, a larger sensor will obviously have bigger pixels and therefore provide better overall image quality.

Let's start from the beginning: in scientific cameras, there are two main categories of technology: 1) CCD (Charge-Coupled Device), and 2) CMOS (Complementary Metal-Oxide-Semiconductor). The differences between these technologies and the way they are configured affect their performance in imaging applications.



CCD technology (on the left) and CMOS technology (on the right)

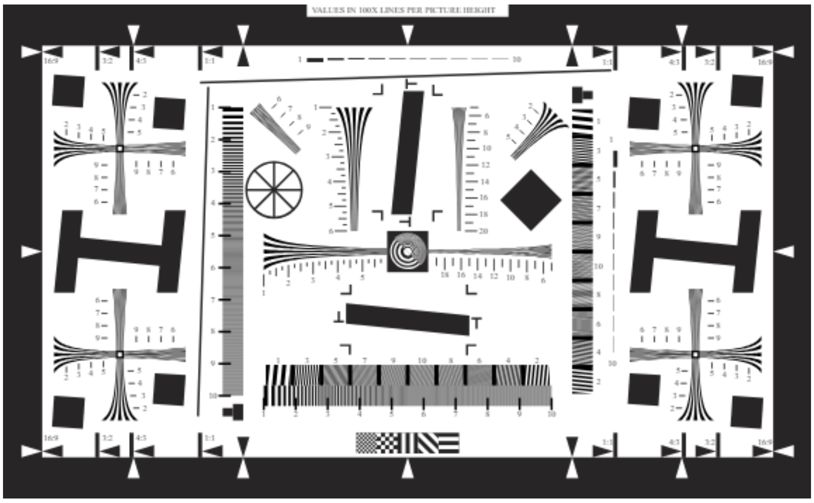
n a CCD, the signal is transferred from each pixel down each column and then shifted horizontally toward a common amplifier. CCDs are characterized by a slower configuration but offer high quality and sensitivity. In a CMOS sensor, the signal is shifted within each column, and each column has its own analog-to-digital converter, allowing for larger sensor sizes. These sensors provide a higher dynamic range compared to CCDs, much faster acquisition speed, and better signal-to-noise ratio with a higher number of pixels, but their sensitivity to very low signal levels is lower than that of CCDs.



CMOS vs CCD: in the low signal intensity range, CCD sensors have higher quantum efficiency (courtesy of Paolo Barzaghi).

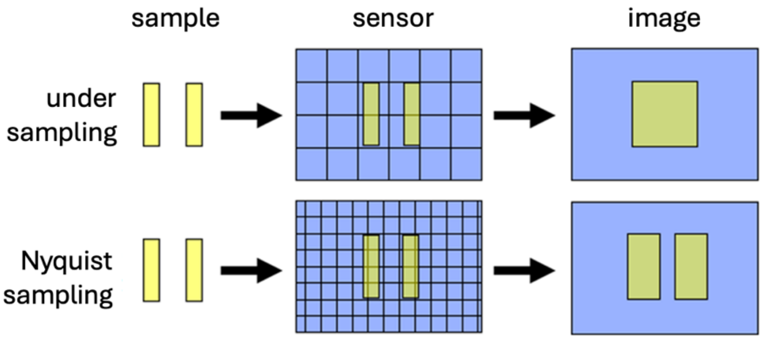
Lenses

At this point, it is important to consider the optical characteristics of the system, particularly the lenses. The resolution of a lens can be evaluated using a specific chart. To understand resolution, we look at pairs of lines: to represent one pair of lines, at least one full row of pixels is needed. When these pairs of lines blend into a uniform gray, the resolution limit has been reached, regardless of the number of pixels in the image.



The ISO standard for measuring the resolution of "electronic still imaging" cameras is ISO 12233, which is available exclusively from the International Organization for Standardization.

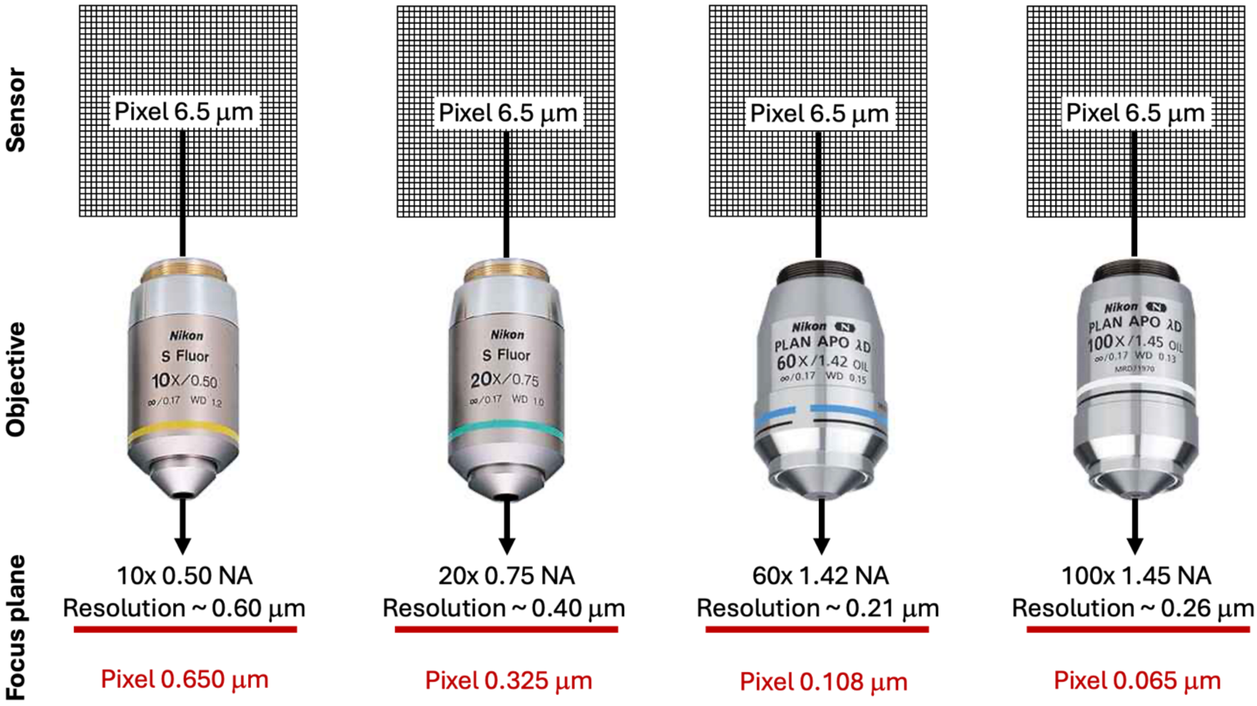
This principle is known as Nyquist sampling, named after the Swedish engineer Harry Nyquist. Essentially, imaging systems relate resolution to the size of a single pixel. To achieve the best possible separation between adjacent features in a sample, there should be at least one pixel between them. This means that higher resolutions require matching at least two camera pixels instead of one. Consequently, the sampling frequency is doubled: the number of pixels is doubled, allowing finer details to be resolved. This doubled sampling frequency is known as Nyquist sampling and establishes that the maximum resolution should be twice as high as the smallest feature size in the sample.



Nyquist sampling: the sensor pixels are half the size of the smallest object, allowing the details within the sample to be resolved.

In microscopy

The resolution of a scientific camera depends on two main factors: the size of the sensor's pixels and the magnification of the objective lens used. Smaller camera pixels and higher magnifications lead to higher resolutions, but the former comes at the expense of sensitivity (larger pixels are more sensitive), and the latter reduces the field of view (higher magnification decreases the image area). The effect of magnification on pixel size is illustrated in the following figure.



How pixel size is influenced by magnification. In this example, a camera sensor with 6.5 µm pixels is used with four different objectives: 10x, 20x, 60x, and 100x. These objectives reduce the effective pixel size on the sample according to their magnification, resulting in relatively smaller pixels at higher magnifications. When using a camera with 6.5 µm pixels and a 60x objective, the pixel size on the sample is 0.108 µm (with an optical resolution of 0.21 µm), resulting in Nyquist-optimized sampling. At higher magnifications (100x), slight oversampling occurs, while at lower magnifications (20x and 10x), progressive undersampling occurs relative to the optical resolution.

Resolution vs. sensor size

Let's suppose you are shooting with a Leica SL2 full-frame camera with 46.7 megapixels. With any lens, you will produce an image of 8368 x 5584 pixels, which spread over a surface of 24 x 36 mm means that each pixel cell has a width of 4.30 µm. Resolution charts are defined in terms of line pairs per millimeter (lp/mm), and naturally, at least two pixel rows are needed to render one line pair. So, calculating this, we get that the theoretical maximum resolution at the sensor level is 116 lp/mm. Of course, this won't be the actual output due to limiting factors such as sensor interpolation or the presence of an anti-aliasing filter when applicable. Here are some sensors compared in order of pixel density.

	Sensor Format (mm)	Megapixel	Max resolution (lp/mm)	Pixel Pitch (µm)
iPhone 15 Pro	1/1.28'' (9.8 x 7.3)	48.0 (8000 x 6000)	410	1.22
Sony RX100 VII	1'' (13.2 x 8.8)	20.1 (5472 x 3648)	207	2.41
Fujifilm X100VI	APS-C (23.5 x 15.7)	40.2 (7728 x 5152)	164	3.04
Olympus OM-1	4/3 (17.4x13.0)	20.4 (5208 x 3916)	150	3.32
Fujifilm GFX100 II	Medium (43.8 x 32.9)	102 (11648 x 8736)	133	3.76
Hasselblad X2D	Medium (43.8 x 32.9)	100 (11656 x 8742)	133	3.76
Leica SL3/M11/Q3	Full Frame (36.0 x 24.0)	60.2 (9520 x 6336)	132	3.78
Sony A7r V	Full Frame (36.0 x 24.0)	60.2 (9504 x 6336)	132	3.79
Canon 5Ds R	Full Frame (36.0 x 24.0)	50.3 (8688 x 5792)	121	4.14
Nikon Z fc	APS-C (23.5 x 15.7)	20.9 (5568 x 3712)	118	4.22
Leica SL2	Full Frame (36.0 x 24.0)	46.7 (8368 x 5584)	116	4.30
Nikon Z8	Full Frame (36.0 x 24.0)	45.7 (8256 x 5504)	115	4.36
Nikon Z6	Full Frame (36.0 x 24.0)	24.3 (6048 x 4024)	84	5.95

We know that pixel density, or pixel pitch, is the number of pixels present per unit area of the sensor. Higher pixel density can lead to higher resolution and therefore more detailed images. However, excessively high pixel density may cause issues such as a reduced signal-to-noise ratio, especially in low-light conditions. Additionally, it is important to consider that the smaller the pixel pitch, the higher the optical quality of the lenses must be to adequately resolve the captured detail densities. Pixel pitch might be a more appropriate benchmark than total megapixels when evaluating camera quality and performance, as it accounts for both pixel density and the physical size of individual pixels on the sensor, directly influencing resolution and other crucial aspects such as light sensitivity and depth of field.

When comparing sensors with the same pixel pitch but different formats, such as the Leica SL3 (Full Frame with a 3.78 µm pixel pitch) and the Hasselblad X2D (Medium Format with a 3.76 µm pixel pitch), several differences emerge beyond mere resolution, particularly in depth of field. Depth of field, which indicates the range of sharpness within a photograph, varies based on sensor size, lens focal length, and aperture. Larger sensors, even with the same pixel pitch, tend to produce a shallower depth of field compared to smaller sensors. This is because sensor size directly influences depth of field: larger sensors generally require longer focal lengths to achieve the same framing. This leads to a relatively wider aperture and, consequently, a narrower depth of field. To better understand this, consider a practical example: a 45mm lens at f/4 on a medium format sensor roughly corresponds to a 35mm lens at f/3.16 on a full-frame sensor (with a crop factor of about 0.79), or a 23mm lens at f/2.1 on an APS-C sensor (with a crop factor of about 1.5x). In other words, it is important to consider the crop factor not only for lens focal length but also for aperture, as both directly affect the depth of field of the resulting image.

Here are some examples comparing the Leica SL3 (Full Frame) and Hasselblad X2D (Medium): this is where you realize it’s not just about pixel pitch or resolution—it’s the combination of sensor format, focal length, and aperture that shapes the perception of space. Because depth and the smoothness of bokeh aren’t something you can read in the specs—they’re something you see with the naked eye.

Leica SL3 (FF) 35mm - 1/25 sec - f/3.2 - ISO 1600

Hasselblad X2D 45mm - 1/15 sec - f/4.0 - ISO 1600

Leica SL3 35mm - 1/30 sec - f/3.2 - ISO 1600

Hasselblad X2D 45mm - 1/13 sec - f/4.0 - ISO 1600

Leica SL3 (FF) 35mm - 1/13 sec - f/3.2 - ISO 1600

Hasselblad X2D 45mm - 1/5 sec - f/4.0-– ISO 1600