FlowCam® Technical Brief

Understanding Sensor Resolution in an Imaging Particle Analysis System

Summary: The concept of sensor resolution in any kind of instrumentation is an extremely important one. Fundamentally, the resolution of any sensor is the minimum change that the sensor can detect in the quantity being measured. In digital imaging, it is important to understand that *spatial resolution* is the most important *quantitative* measurement.

Definitions:

Spatial Resolution: In an imaging system, spatial resolution is a measurement of how small an object can be resolved by the system. This is usually expressed as line pairs per unit distance, where a line pair is a dark line adjacent to a white line of the same width. It is important to note that spatial resolution is related to, but not always dependant on the pixel resolution, as shown in Figure 1. In *qualitative terms*, higher spatial resolution yields a *sharper* image, regardless of pixel resolution.

Pixel Resolution: The pixel resolution of a sensor is usually expressed in terms of the total number of *active* pixels used to form the digital image in terms of X and Y dimensions (i.e. 1024 pixels wide x 768 pixels high). Pixel resolution makes the most sense when it is expressed as a unit of length of the sensor's projected pixel dimensions *on the object being imaged* (i.e. in the object space) as shown in Figure 2.

What do we really want to measure?: In an imaging particle analysis system, the question most people really want to answer is "what is the smallest particle I can actually measure with the system?" But the question needs to go further than just particle *size* for imaging systems, since the desired measurement may be something more complex like "fiber length". Luckily, a good idea of the answer can be found by taking the "pixel resolution" as shown in Figure 1, and working forward from there to determine what size object can be resolved by the system.

The pixel resolution, expressed as sensor pixel size projected onto the object plane, is easily determined by measuring an object of known size (such as a measuring reticle) in the

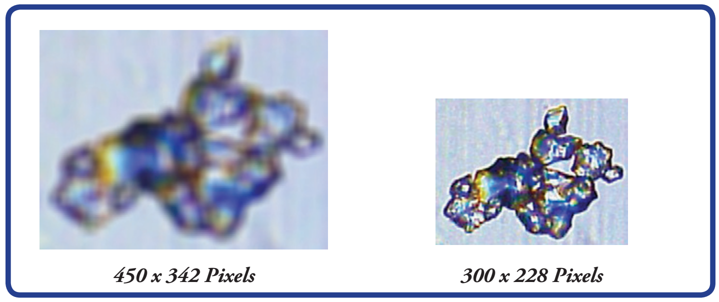

Figure 1: The image on left has a higher pixel resolution (450x342), but a much lower spatial resolution than the one on the right (300x228).

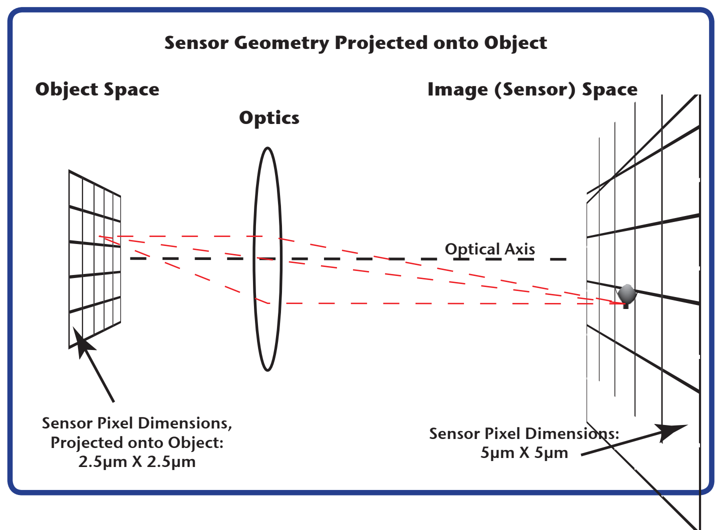

Figure 2: "Pixel resolution" expressed as the sensor pixel size projected onto the object. In this case, the overall magnification is 2x, and the meaningful definition of pixel resolution is 2.5µm/pixel.

object plane, and dividing by the number of pixels that covers the reference object. So, if a 10µm distance in the object plane uses 10 pixels on the sensor, then the pixel resolution at the object is 1µm/pixel.

Sampling theory tells us we need at least 2 samples (pixels) to count an object, so we would say for this system we can count 2µm and larger particles. But if we want to make shape measurements, then we need more pixels, and the sophistication of the shape measurement desired will determine how many pixels are needed. Perhaps an image as small as 4x4 pixels will suffice for differentiating rods and spheres by aspect ratio. But for higher level measurements like circularity, a starting point might be a minimum of 10x10 pixels. A detailed discussion of this topic can be found in the white paper: *Imaging Particle Analysis: Resolution and Sampling Considerations* available on the Fluid Imaging web site.

The Most Common Measurement of Spatial Resolution:
As briefly outlined in the definition of spatial resolution, the most common measurement is expressed in terms of line pairs/unit distance. Typically, a resolution target (such as USAF 1951, or sinusoidal target) containing different (known) spatial resolution line pairs is imaged by the system.

In the original target, each line pair has a known physical spacing. The modulation of the target is the original difference in values (on the target) between the lightest and darkest parts of the line pair or grey scale sine wave. For simplicity's sake, let us assume that a value of zero (0) represents the darkest part of the target, and 255 represents the lightest part of the target. This is typical of an 8-bit grayscale value as represented by most cameras, where one byte (256 levels) is used to describe the intensity of each pixel value.

Once the target is imaged, the modulation of the target's image formed by the optics is measured in the same way. It is important to note that since a digital camera is being used to measure the image, the modulation transfer measurement is a system measurement, including the illumination, optics and sensor (camera). In the example shown in Figure 3 above, the resultant system image of the target showed a modulation of 50 levels, representing a roughly 20% modulation transfer for the system at this spatial resolution (10 line pairs/mm).

The Modulation Transfer Function (MTF) is simply a plot of the system's modulation in the image of the target for different input frequencies as shown in Figure 4. MTF plots are the most frequently used optical system characterization method used in industry. However, this is a continuous plot, with modulation ranging from 0-1 (0% to 100%) depending on the input spatial frequency. To describe the resolution of the system, what is typically done is to define a modulation value which is considered the limit at which an image is acceptable for the information we are trying to extract.

One might typically define acceptable resolution as 30% modulation. We can then use the MTF plot to find out at what input spatial frequency we get 30% modulation, and call that the "resolution limit" of the system. So, in Figure 4, we could see that in this particular system, a 30% modulation in the output image occurs at 34 line pairs/mm, so that would be defined as the limit for this system.

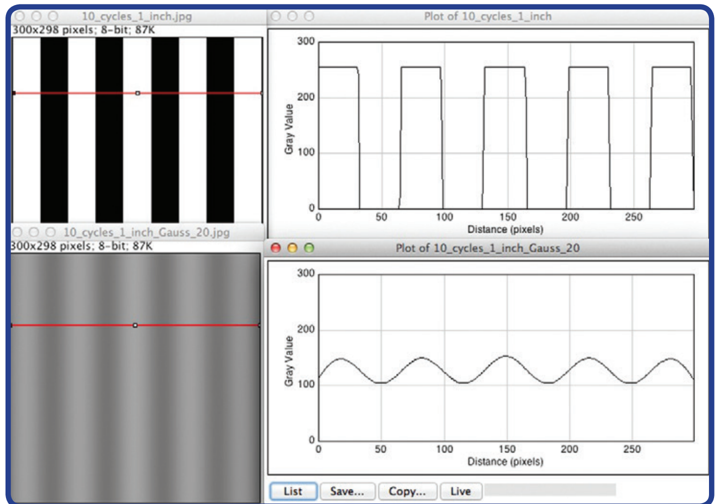

Figure 3: Depiction of an optical system having around a 20% modulation value when imaging a bar target at 10 line pairs/mm. The original target had a gray scale range of 0-255, and the resultant image has a gray scale range of 100-150, or 50/256 ≈ 20% modulation transferred.

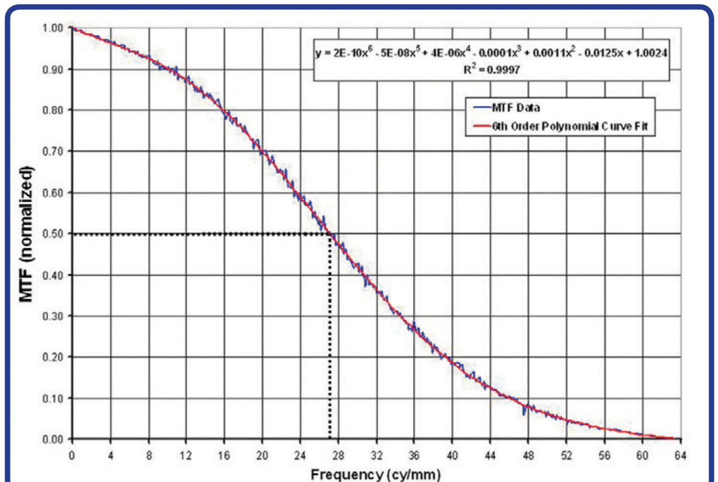

Figure 4: Typical Modulation Transfer Function (MTF) plot. (https://en.wikipedia.org/wiki/File:MTF_example_graph.jpg)

Conclusion: The point of all of this is to say that sensor resolution in an imaging particle system is a complex topic, with the answer often being reliant upon what measurement one wants to resolve, and how well you want to resolve it. Rather than relying upon vendor specifications, it is recommended that the user define the target sensor resolution in the terms that are important to the measurement one wishes to capture, and then discuss this value with prospective vendors. In most cases, the only way to confidently know if the system's resolution will work for an application is to image a sample in the instrument to insure that the desired discrimination of particle types can be made.