Is your Lens the Weakest Link in your Hi-resolution Application?

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EXECUTIVE SUMMARY

As if there weren't enough to consider in machine vision applications, today's megapixel cameras present a unique set of challenges. One factor that may be taken fro granted is the lens selection. Below are some factors to think about when considering a lens for a high-resolution inspection application.

Today's smartphone proliferation has resulted in competitive megapixel chips available for a variety of digital cameras. DSLR and industrial cameras with megapixel sensor arrays are available at reasonable prices. Sensor chips are getting bigger and pixels are getting smaller, and lens manufacturers have introduced a variety of megapixel lenses to keep pace with camera technology.

The image quality of smartphones and DSLR cameras is often judged by what pleases the human eye. These cameras employ software for image enhancement based on the preference of the viewer. Industrial cameras are used for inspection and gauging. They use the raw video from which the image processor can extract information. Sometimes the image is not even humanly discernable from the part that is inspected. The quality of pure information recognizable by a machine is paramount here. This attention to accuracy has a price, which is the cost of quality in machine vision systems. For more discussion of this, I invite you to read my article, "Why Don't We Inspect Parts with Smartphones".

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Camera Resolution and Lens MTF

The Camera

When we are designing a machine vision system, two of our most important considerations are the sizes of the part and the defect. That is, what is our Field of View (FOV) and within that FOV what is the smallest defect we can reliably detect? Let's say the part is 40mm square and we need to detect a .02mm defect. The following formula determines the camera resolution required:

FOV/ Defect size = Number of gradations (pixels)

40mm/ .02mm = 2,000

This provides the minimum number of required pixels in one axis. (Note that this is just a starting point regarding the lens and camera. There are other variables to consider such as defect type and software that are beyond the scope of this article. This discussion concerns only the Megapixel camera with its unique considerations regarding lens selection).

Consulting a camera selector available from a number of camera manufacturers (I selected the one on the [IDS website](), *a 6-megapixel camera has a raw pixel resolution of 3088 x 2076, which meets the minimum 2000 pixel requirement. Referring to the camera specification, we note that the sensor format is 1/1.8". This number refers to*

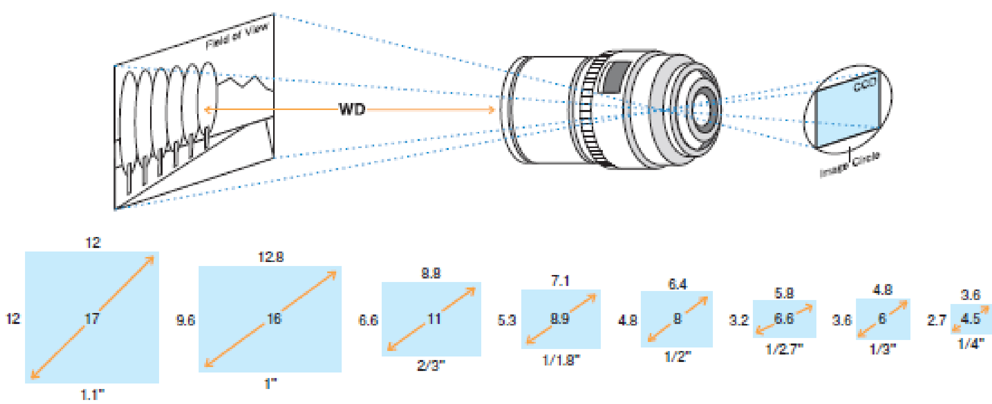

Figure 1: Sensor Formats (Source: Computar Lens Product Guide)

the size and shape of the sensor. Below is a graphical representation of the dimensions for some popular sensors.

The dimensions for the example sensor are:

Diag	*Width*	*Height*	*Area*
8.93	*7.18*	*5.32*	*38.20*

We also note that the pixel size for our camera sensor is 2.4µm. These two factors are critical for our lens selection.

The Lens

Just as camera have resolution specifications, so too do lenses. Camera sensors are mechanical assemblies and, as such, are extremely repeatable across their x and y-axes. Lenses are ground or molded from high-quality silica. This process yields aberrations within the glass itself. In addition, the multi-stage lens manufacturing process also introduces aberrations. These may take the forms of Spherical Aberration, Astigmatism, Coma, Field Curvature, Geometric Distortion, Keystone Distortion and Chromic Aberration. They occur to some degree in all lenses and are not unique to megapixel lenses. They are mentioned here for reference and are discussed in detail elsewhere.

Megapixel lens

Megapixel lenses are those which have been manufactured to higher quality standards to meet the resolution requirements of the smaller, more dense pixe

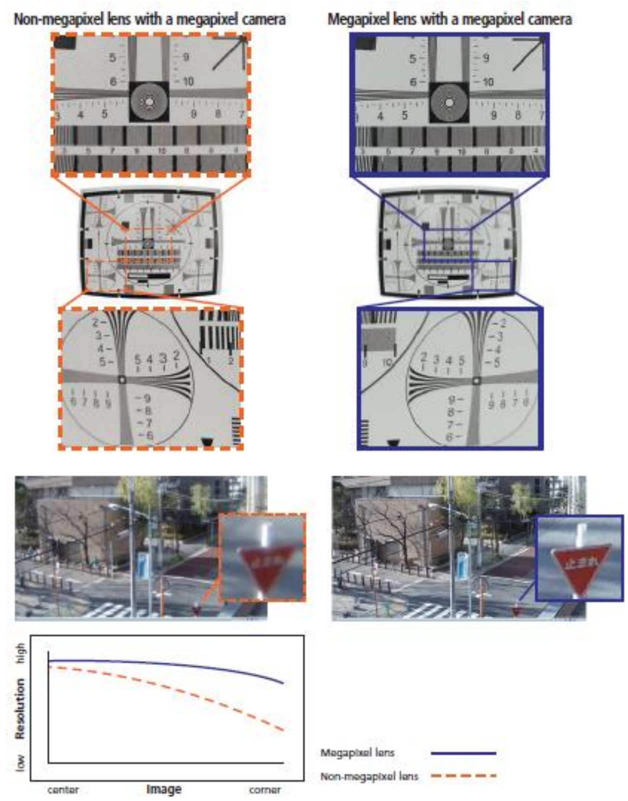

Figure 2: Optical Aberrations, Non-megapixel vs. megapixel lens. Source: Computar Lens Product Guide2016

The picture on the right illustrates several the aberrations encountered when applying a non-megapixel lens to a megapixel camera.

Modulation Transfer Function (MTF)

Wikipedia has an excellent technical discussion of [MTF](https://en.wikipedia.org/wiki/Optical_transfer_function) (Wikipedia, 2016). The concept is easily understood by looking at Figure 3. Note how the dot in (b) is much sharper than that in (e). The reason for this is that the lens is able to resolve a smaller area. The circular targets in (c) and (f) consist of light and dark areas, which become smaller towards the center of the circle. Modulation Transfer Function is defined as the response to a periodic alternating (sine) wave pattern. It is essentially a measure of the quality of the light transmission through the lens. The more repeatable the lens, the better the light transfer and the smaller the areas of contrast that can be seen. Observe that in image (c), the contrast is much sharper in smaller increments. MTF is often specified in “Line pairs per millimeter” with a higher value indicating a higher quality lens.

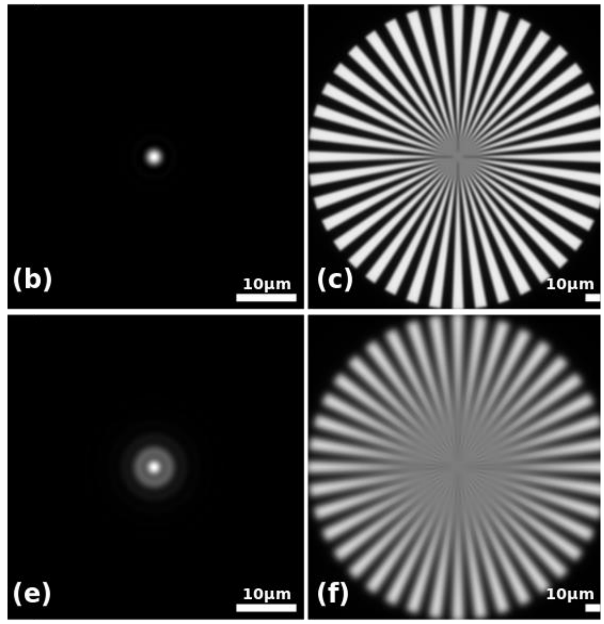

Figure 3: Source: Wikipedia, https://en.wikipedia.org/wiki/Optical_transfer_function

To further complicate matters, MTF is different in the center of the lens from that at locations further from the center. This is because, by design, a lens distorts the light that passes through it in order to achieve the desired effects. For that reason, manufacturers will provide a graph illustrating MTF at various distances from the center of the lens.

Figure 4 is a typical MTF graph. The y-axis is the “Modulus of the OTF”, essentially a measure of the percentage of contrast; while the x-axis is the spatial frequency, a measure of the distance between contrasting areas as illustrated in Figure 3. What the chart illustrates is the degree of contrast differentiation lost as the spatial frequency increases. Or, the closer together two contrasting objects are, the more difficult it is to differentiate between the two due to the resolution of the lens. Because MTF varies with the curvature of the lens, multiple graphs are provided at various distances from the center of the lens. Thus, one may select the most conservative results, if necessary.

Comparing the MTF graph with our camera spatial frequency:

(3088 pixels/ 7.18mm)/ 2 = 215 pixels/ mm.

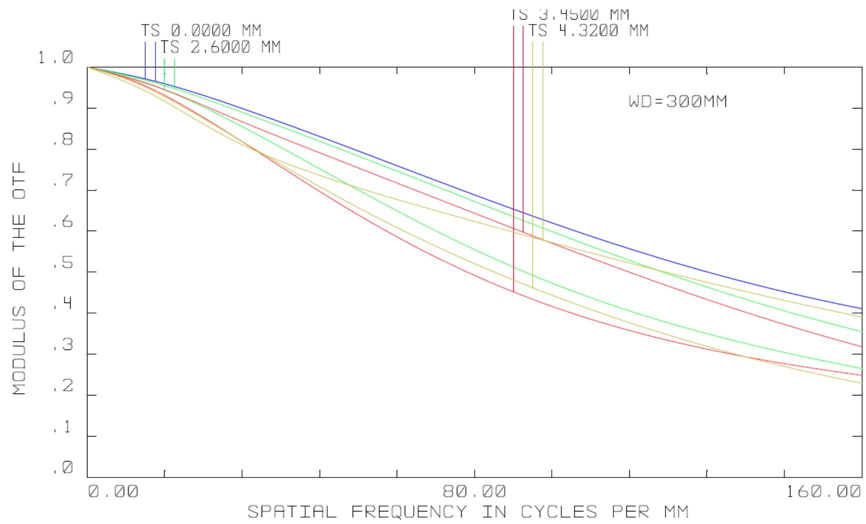

Figure 4: Typical MTF chart. Source: Computar

The lens illustrated in Figure 4 has a maximum spatial frequency of 160 cycles/ mm. Therefore, the best achievable resolution is not the 6 Megapixels of the camera, but approximately 75% of that or 4 Megapixels. In addition, it is advantageous to apply a lens at no less than 50% contrast, which brings the resolution to 2 Megapixels. The results here are that the lens may indeed be a weak link.

Conclusion

In the early years of machine vision, MTF was not as important as it is today. The typical analog camera had 300 lines and lens quality far exceeded that. Even the advent of VGA digital cameras at 640 x 480 pixels allowed the use of security-type lenses for all but the most critical gauging applications. Today, however, when *selecting a megapixel camera to achieve the desired resolution it is imperative that a matching megapixel lens be employed. A manufacturer's MTF chart is an invaluable resource in determining whether the spatial frequency of the lens and the resolution of the camera are compatible.*

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