FUNDAMENTALS OF SELECTING A LENS

Prepared by: Channel Systems Inc

July 2009

Fundamentals of Selecting a Lens

It's very important to know what you're looking for before trying to find the lens that's right for you. Software can't fix a bad lens. The more you know about what you need, the better the lens you will find. Below is a brief explanation of the common measurements and specifications in lenses that have an impact on the quality of your image.

Resolution and F/#

The resolution for a camera is effectively the size of the pixel. Smaller pixels mean more of them will go into building the same image, giving it sharper corners and overall better definition. When choosing a lens, however, resolution can be tricky.

Matching a resolution for a camera and a lens is important. The wrong choice could waste money or provide a poor quality image. For the best possible resolution, the lens' f/# and camera's pixel size should match as shown below.

Pixel sizes are generally measured in micrometers, while F# are seemingly arbitrary values. The F/# is the Focal Length (the F) over the Lens Aperture (the #).

$$F/\# = \frac{focal\ length}{lens\ aperture}$$

Having an f/# is the first step, but there's another step before it can be used. This f/# is for an object infinitely far away, while at the relatively short distances of machine vision the f/# needs to be modified. The equation is as follows

ff/#=(f/#)(Magnification + 1)

Where ff/# is the finite f/#. As an example where the image is not magnified (Magnification of 1), the ff/# is twice the f/#. As magnification increases, ever smaller f/# are required to provide the same results.

Once the ff/# has been calculated, it's possible to solve for the minimum supported pixel size. The units will be in whatever the wavelength is measured in.

$$ADD = (2.44)(ff/\#)(\lambda)$$

Lambda is the wavelength of light that will pass through the lens (Visible light is 0.4µm to 0.7µm, 0.630 is a good benchmark). ADD is short for the Airy disk diameter, which is the minimum amount of space that light will magnify on a point. This space will be the minimum supported pixel size of the lens.

Ex. A lens listed f/2.8 with a magnification of 2X

f/2.8

ff/# = 2.8(2+1) = 8.4

ADD = (2.44)(8.4)(.630µm) = 12.91µm

This means that the smallest pixel size this lens will match is 12.91µm.

Having a low f/# will lower the ADD and allow higher resolutions, however this gets more and more expensive and difficult to manufacture. Having a camera with a lower pixel size than the lens' ADD is fine, but the image quality will be dependent on the lens, not the camera. Conversely, having a lower ADD than pixel size will limit the image by the camera. For the best resolution, choose the lens that has an ADD around the camera's pixel size, preferably lower.

$ADD < Pixel\ Size$ Camera Limited

$ADD > Pixel\ Size$ Lens Limited

Depth of Field

While a low f/# is definitely important for resolution, there are some drawbacks to using too low of an f/#.

Depth of field is the range of distances that an object will be in sharp focus. By definition however, "sharp focus" is subjective. In contradiction to resolution, the higher the f/# is, the higher the depth of field is, however, the Depth of Field increases at a higher rate than the resolution decreases. A higher f/ # provides a larger Depth of Field.

Contrast (also known as modulation) is the difference between the lightest and the darkest pixel of an image. A high contrast makes pictures appear sharp, even at low resolutions. Like Depth of Field, Contrast is greater at high f/#'s. Balancing the f/# and Contrast/Depth of Field are important.

Distortion

Distortion is a lens aberration that causes objects to be shown either farther or closer to the optical axis than expected. This is actually part of the lens design and not a manufacturing error. Most lenses will have some noticeable distortion and the effect is relative to the area of the field in which it is measured. For example, 2% distortion over a distance of 100 pixels will cause this distance to appear as 102, but 400 will appear as 408, 500 as 510 etc.

Magnification

Magnification is the relative change in size of the real image on the camera's sensor and the size of the object. To fit the image on the sensor, the formula for the minimum required magnification is below.

$$mag = \frac{W_{camera}}{W_{FOV}}$$

W_{camera} is the width of the camera's sensor and W_{FOV} is the width of the FOV.

Working Distance

This is the distance between the object being imaged and the lens. Typically, a long working distance requires a larger and more expensive lens than a short distance would.

Sensor Size & Field of View

The size of a camera's sensor is also an important factor when choosing a lens. Below is a table listing the common sensor sizes used in machine vision and the method to calculate the necessary distances or dimensions that match these lenses.

Sensor Size	1"	2/3"	1/2"	1/3"	1/4"
H	$\frac{12.8*L}{f}$	$\frac{9.6*L}{f}$	$\frac{6.4*L}{f}$	$\frac{4.8*L}{f}$	$\frac{3.6*L}{f}$
V	$\frac{9.6*L}{f}$	$\frac{6.6*L}{f}$	$\frac{4.8*L}{f}$	$\frac{3.6*L}{f}$	$\frac{2.7*L}{f}$

f = Focal length of the lens in mm
H = Horizontal Dimensions of the object
V = Vertical Dimensions of the object
L = Distance from the lens to the object
H, V, and L must be in the same measurement.

Ex. Camera 2m from target with a 35mm lens and a 2/3" sensor

$$H = \frac{9.6*2}{35} = 0.55$$

$$V = \frac{6.6*2}{35} = 0.377$$

At this range, the camera would have a 0.55 X 0.377 meter field of view.

Most of the time in machine vision, everything but f is known. In this case, use either the H or V equation that matches the size of your camera's sensor to solve for f. Whenever possible, round the focal length down. This will increase the field of view, assuring full coverage of the object.

Field of View (FOV) is the object area that is imaged by the lens onto the camera's sensor. Overshooting your camera sensor's dimensions (10% is plenty) is recommended to cover any alignment errors and uncertainties in magnification.

Balancing all of these factors is key in choosing a lens. Depending on the application and required tolerance, there are drastically different options in choosing a lens. Choose what is appropriate for your specific situation.