Seven Important Factors When Selecting a Machine Vision Lens

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EXECUTIVE SUMMARY

As technology and mobility continue to drive machine vision application techniques from industrial to commercial, no longer are fixed focal length lenses with manual irises the only solutions used by the professional. This brief article highlights some of the more common features and functions of lenses used in machine vision.

Simply put, a lens focuses the world onto the medium in question. It can be as simple as the pinhole lens used to view a solar eclipse, the medium for which is a piece of cardboard, or as complex as the Corrective Optics Space Telescope Axial Replacement on the Hubble space telescope, the medium for which is a charged coupled device (CCD). Somewhere in between these two extremes is a variety of effective and affordable lens solutions used with machine vision cameras. These lenses focus light from an object of interest. The most common types of these lenses are described in this white paper.

CONTENTS

Primary Lens Considerations

When selecting a lens for a machine vision application, several factors are considered. What is the distance between the object to be inspected and the camera, i.e. the Working Distance(WD)? This will affect the focus and focal length of the lens. What is the size of the object? This determines the Field Of View (FOV). What is the size of the defect to be detected? The resolution of the sensor and thus the image sensor and pixel size are determined here, as well as whether camera motion or special fixturing may be required. What are the lighting conditions? Can the lighting be controlled or is the object luminous or in a luminous environment? Is the object or camera moving or stationary? If moving, how fast? Motion between the object and camera have shutter speed implications, which also affects the light entering the lens and the f-Number. These variables and more make selecting the proper lens a challenge, but fundamentally one may begin with the three main types by feature: type of focusing, type of iris and focal length (Computar, 2016).
Focus describes how clearly the image from the world is replicated on the sensor; it may be adjusted either manually or automatically. Focal length refers to the distance between the optical center of the lens and the surface of the imaging sensor and determines magnification. Lenses are available with either fixed or variable focal lengths and may be manually adjusted or automatic. The iris controls the amount of light that reaches the camera sensor. This, too, may be either manually or automatically adjusted and may even be software controlled in conjunction with the camera iris.

Focus

An object is in focus when a point source of light traveling through a lens yields the smallest area on the sensor or medium. Lenses may have a manual or automatic adjustment. Focus may be adjusted either manually or automatically (autofocus).

Manual Focus

As its name implies, a manual focus lens is adjusted manually by the operator observing an image. A manual fixed focal length lens will typically have two adjustment rings, one for the aperture (iris) and one for a "fine" focus adjustment within the Depth Of field (DOF). Manual focus lenses are used where the WD is constant, such as in a typical factory automation application.

AutoFocus

Autofocus lenses have a built-in motor to change the focus of the lens. Note that an autofocus lens does not change the focal length (see varifocal, below); it simply adjusts for optimal focus with the Depth Of Field. Autofocus lenses provide a signal to the motor either "actively" with a distance sensor or passively" with software. The operator selects the object scene that is to be in focus and the autofocus lens will then vary the lens focus as the object WD changes. Autofocus lenses are commonly built into smart cameras to improve image quality for inspections where the object's working distance may vary slightly, such as packages coming down a conveyor.

Focal Length

Focal length refers to the distance between the optical center of the lens and the surface of the camera sensor. Focal length is a factor in the transformation in apparent size between the world and the sensor (magnification). For machine vision applications where the Field Of View and Working Distance are constant, the simple, compact design of a Fixed Focal Length lens is preferred. Varifocal lenses are useful for machine vision applications and demonstrations where one may readily evaluate an application or demonstrate a variety of features without changing the lens.

Figure 1: Fixed Focal Length Lens (Computar)

Fixed Focal Length

Fewer optical components result in lower cost, and because these lenses have fewer optical components, or stages, through which the light must pass, optical distortion is minimized. As the name implies, the focal length of a fixed focal length lens is a function of its mechanical design, and cannot be changed. Common available fixed focal lengths are 8mm, 16mm, 25mm, and 50mm. Because of their simplicity, fixed focal length lenses may be either manually or automatically adjusted (autofocus).

Varifocal

A varifocal lens has an adjustment enabling the operator to change the focal length of the lens. This adjustment changes the magnification and Field Of View for a given Working Distance. When the focal length is changed, the lens must be refocused at the new setting. Commonly available ranges for varifocal lenses are 4-8mm, 8.5-50mm, and 12-36mm. A varifocal lens will typically have three adjustments: one for the iris (aperture), one for the focal length and one for the focus.

Figure 2: Varifocal Lens (Computar)

Zoom

A zoom lens is a complex lens that maintains its focus while its focal length changes. This adjustment changes the magnification and Field of View. Often the term "zoom" is misapplied to varifocal lenses (above). Due to their mechanical complexity and distortion potential, zoom lenses are rarely used for machine vision applications but are useful for some demonstrations and evaluations.

Iris

The iris determines the amount of light that reaches the camera sensor by varying the size of the aperture. Too much light can reduce the contrast of the image and too little light can make features indiscernible. The iris is a leaf diaphragm

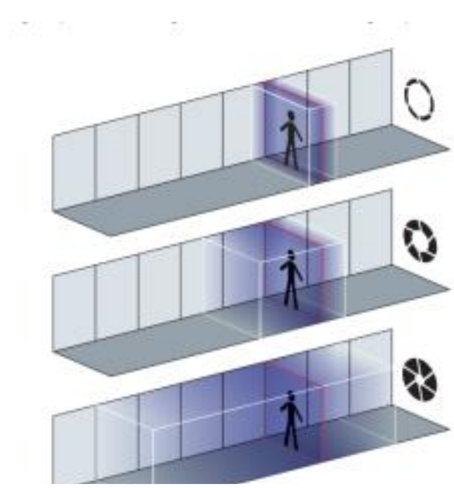

Figure 3: Depth of Field Illustration (Computar)

(Burke, 1966), the opening of which may be adjusted either manually or automatically. Machine vision applications where the light level is controlled, such as in factory automation would use a manual iris, while those, such as outdoor inspection applications would use an automatic iris. If the iris control is automatic, the control method is either DC, Video or P-iris.

Note that leaf diaphragm irises share a common design characteristic, they affect focus and depth of field. Depth of field refers to the range of distances from the lens in which the image will remain in focus. This is a function of the angle at which light enters the lens. A fully open aperture will have a smaller range that of one that is more closed.

Manual Iris

Figure 4: Manual Iris Lens (Computar)

Lenses with a manual iris are generally used where the light level is controlled, such as indoor inspection. Because of the depth of field effect mentioned above, many applications will optimize performance with a high light level and a reduced aperture adjustment.

Auto Iris

It is not always possible to have a machine vision application where the lighting is tightly controlled. Outdoor license plate reading and rail car ID are two examples. In these instances, it is useful to employ an auto iris lens. There are three types of auto iris control: DC, Video, and P-Iris.

DC Auto Iris

DC Auto iris lenses are controlled by a DC signal from a supported camera. This signal is proportional to the amount of light that reaches the camera and is applied to a DC motor. The motor drives against a spring to open the aperture; spring tension closes it. This technique of having a continuously adjusting motor signal implies that the iris is continuously being adjusted.

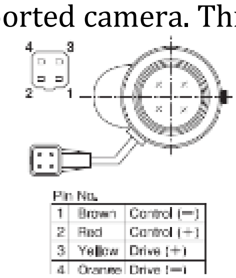

Figure 5:DC Iris Control (Computar)

Video Auto Iris

The Video Auto Iris lens functions similarly to the DC Auto Iris. The primary difference is that a Video Auto Iris lens receives a video signal from a supported camera. This signal is proportional to the light level that reaches the camera and is amplified by circuitry in the lens.

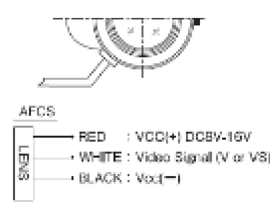

Figure 6: Video Iris Control (Computar)

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P-Iris (Precise Iris)

Today's megapixel camera sensors have pixels so small that, if the light level is very low due to a constricted aperture there is a potential for image blur due to diffraction (Axis Communications, 2010). All lenses have aberrations and, as the light level increases, the intensity may spread across several pixels in the camera sensor. This effect is exacerbated as pixels become smaller. In conjunction with a supported camera, the P-Iris automatically adjusts the iris setting allowing the selection of the best quality or best depth of field while delivering the highest sensitivity for the application (Computar, 2016). Unlike a DC-iris or Video iris lens, the main task of the P-Iris control is not to continuously adjust the flow of light through the lens. It is to improve image quality by enabling the optimal iris position to be set so that the central and best-performing part of the lens is used most of the time, and the camera gain is adjusted for light level. (Axis Communications, 2010)

Figure 7: P-Iris Lens (Computar)

Other Lens Considerations

3 Motor Lens

Complex lenses are available with motorized focus, iris, and zoom. These lenses allow independent remote control of each parameter. Machine vision applications for this type of lens are outdoor inspection and ID of varying object dimensions.

Preset for focus and zoom

An optional potentiometer may be added to the focus/ zoom circuit to be preset for a given Working Distance. Machine vision applications for this lens are sports event timing.

Spot Filter

If the illumination range is high, an optional spot filter may be used. A spot filter is an area of lower transmissivity at the center of the lens. It has minimal effect

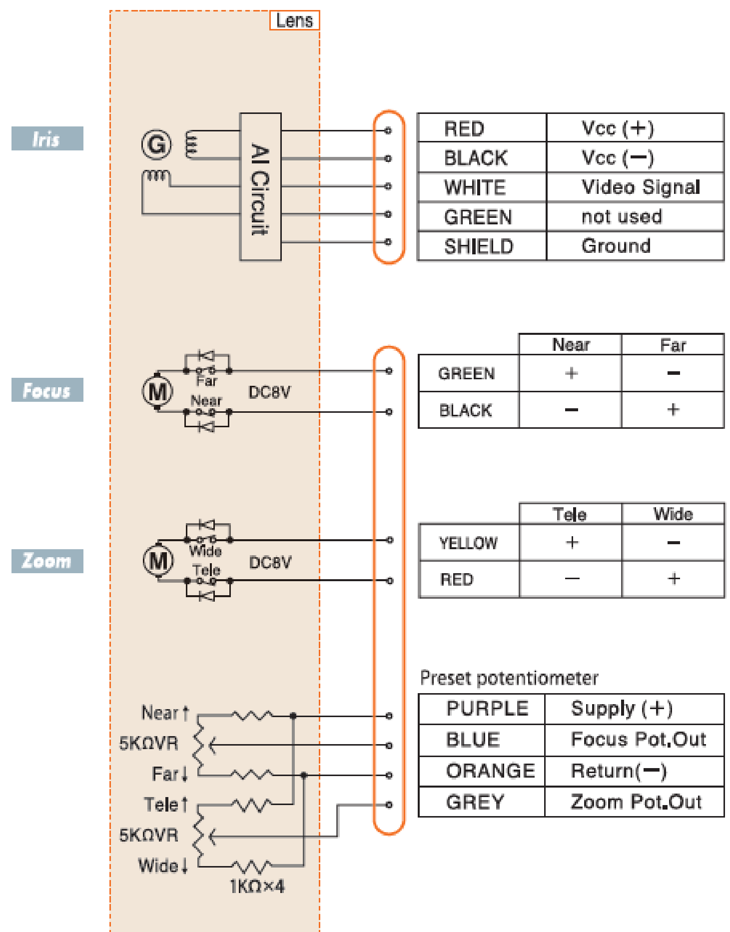

Figure 8: 3-motor Lens Control (Computar)

on a fully open aperture, but as the iris closes its contribution to reducing the light entering the lens increases. Use of a spot filter can significantly increase optical system dynamic range. Machine vision applications for this option are blast furnace inspections.

Megapixel Lens

Historically, analog video cameras captured images with 320 horizontal lines and early machine vision systems customarily coupled these cameras with security lenses. A common test specification for the resolution of a lens is line pairs per millimeter (lp/mm). This describes the minimum distance the lens can resolve the difference between equal sized black and white reference objects. Then, lens resolution exceeded that of the cameras, so camera resolution was the primary concern. Even with the advent of digital cameras with VGA resolution of 640 x 480 pixels, security lens quality was sufficient so as not to be a resolution bottleneck. Today's high resolution, megapixel cameras exceed the resolution of security type lenses. A 5MP camera will not perform at its specified resolution unless the lens resolution meets or exceeds that of the camera sensor. Additionally, the format of the camera needs to be considered to avoid vignetting and the size of the pixels on the sensor should be compatible with the lens resolution. The term "line pairs per millimeter" has no meaning in the digital world. To correlate lens resolution to digital camera resolution, one needs to know the size and number of pixels of the sensor. Line pairs per millimeter can thus be translated into line pairs per pixel (lp/px). Additionally, lens resolution can change from the center of the lens to the outer diameter. To address both issues for demanding machine vision applications, it is advisable to obtain the MTF chart for that lens from the manufacturer.
An MTF chart is the result of testing of the lens. The chart below compares the

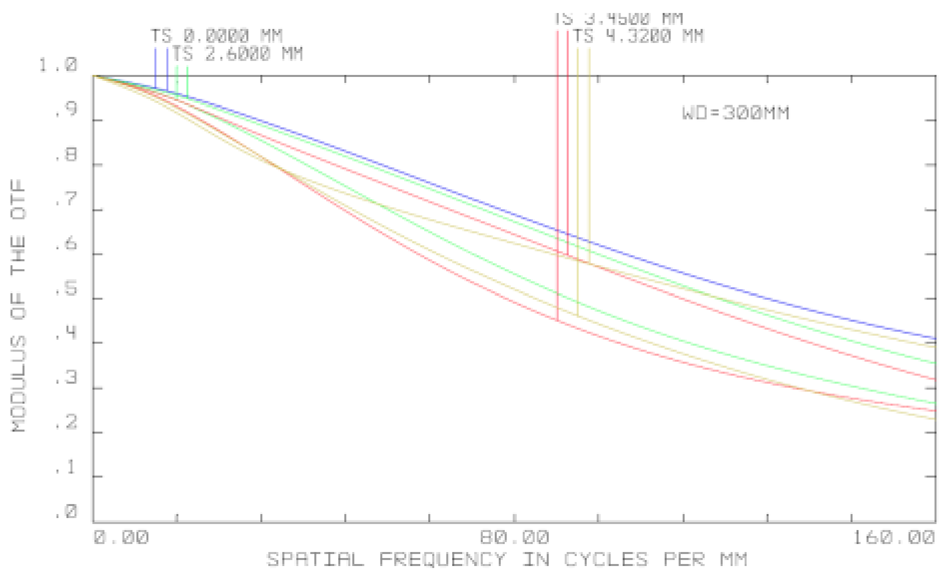

Figure 9: MTF Chart (Computar)

spatial frequency versus the amount of contrast at a Working Distance of 320mm at four distances from the center shown in different colors. There are two curves for each diameter, one for the horizontal test pattern and one for the vertical.
To simplify the lens selection process, lens manufacturers specify the "megapixels" a given lens will support (1.5MP, 2MP, 5MP, etc.) However, for a machine vision application where resolution is important (measurement, gauging), it is important to obtain the MTF chart.

Glossary

Aperture

The opening created by the iris of the lens. The relative size of the opening is described as the f-number.

Autofocus

The automatic adjustment of the focal length of a lens so that a preselected object's image remains in focus as its distance from the lens changes. Autofocus lenses may be either active (transmitting and receiving a signal) or passive (analyzing the image with software).

Depth of Field (DOF)

There is only one distance at which a given lens focal length will provide a focused image. For machine vision applications, this is where a point source of light will produce the smallest point on the vision sensor chip. There is, however, a range within which the point source, although producing a circle on the sensor ("circle of confusion"), can still be analyzed as a point source. This range constitutes the depth of field.

In addition to the "circle of confusion", other factors that influence the depth of field are movement of the object, distance to the object, lens focal length, lens f-number, the size of the image sensor chip and size of the image sensor pixels.

f-Number (f/N)

f-Number refers to the speed of the lens. It is a ration between the size of the aperture and the focal length of the camera. The amount of light entering the lens decreases and Depth of Field increases with an increasing f-Number. Lenses with smaller minimum f-numbers have larger apertures and are called "fast" lenses because images acquired at fast shutter speeds can receive more light than "slower" lenses.

Field of View (FOV)

The area of the "world" that is captured by a lens and transmitted to the vision sensor chip. For machine vision applications, an approximate FOV may be calculated as follows:
FOV = h x WD/ f

Where:

FOV = Horizontal Field Of View in mm
h = horizontal dimension of the sensor in mm
WD = working distance in mm
f = focal length in mm

This is an estimate because exact distances between optical center and sensor surface are often not readily available.

Focal Length

The focal length of a lens is defined as the distance over which initially collimated rays of light are brought to a focus (Wikipedia, 2016). Nominally, it is the distance between the optical center of the lens and the surface of the vision sensor chip. As this distance decreases the light is bent further providing a wider angle of view and increased distortion (wide angle); as this distance increases the light is bent less providing a narrower angle of view and decreased distortion (telephoto).
For machine vision applications, the required focal length may be approximated using the following formula:
f = h x WD/ horizontal FOV

where:

f = focal length in mm
h = horizontal dimension of the sensor in mm
WD = working distance in mm
horizontal Field Of View in mm

This is an estimate because exact distances between optical center and sensor surface are often not readily available.

Focus

The lens setting at which a point source of light traveling through a lens yields the smallest area on the sensor or medium.

Image Sensor Format and Pixel Size

Imaging sensor chips come in a variety of sizes, both in dimensional format and in pixel size. Both are important considerations for machine vision applications and proper lens selection. Below is an illustration of common sensor formats.

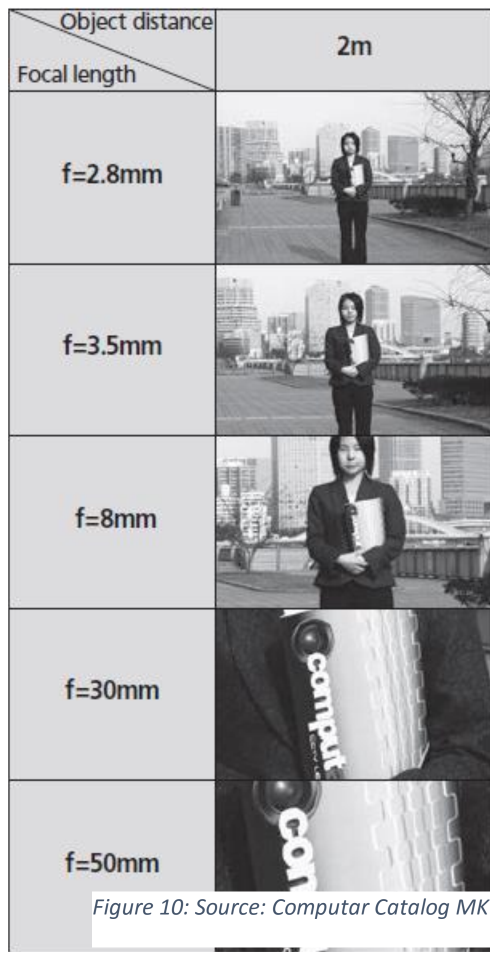

Figure 10: Source: Computar Catalog MKT-CO-CAT

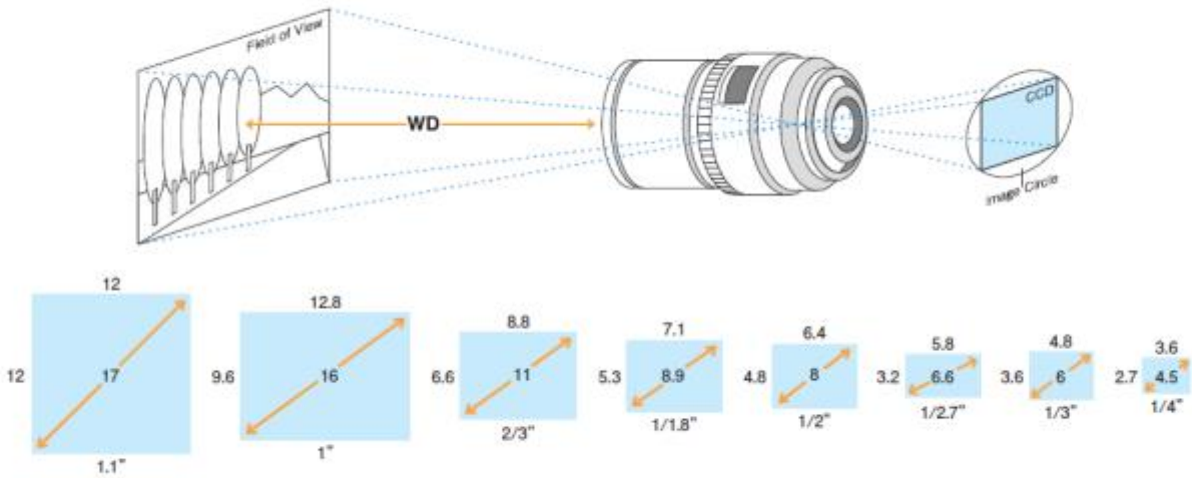

Figure 11: Source: Computar Catalog MKT-CO-CAT

Today's average pixel size is approximately 2.2µm.

Iris (Aperture)

The iris controls the amount of light from the world that reaches the imaging sensor. It may be either manually adjusted or automatic. If automatic, it may be either a lens component or a camera component. All types vary the light level mechanically.

Figure 12: Source: Computar Catalog MKT-CO-CAT

Manual iris lenses are used where the lighting level is relatively constant. This applies to most machine vision applications. If light levels are expected to change, then an automatic iris may be preferred.

Working Distance (WD)

The distance between the optical center of a lens and the object that will be in focus for a given lens focal length. An approximation of WD may be obtained with the following formula:
WD = f / (h x horizontal FOV)
where:

- WD = working distance in mm
- f = focal length in mm
- h = horizontal dimension of the sensor in mm
- horizontal Field Of View in mm

This is an estimate because exact distances between optical center and sensor surface are often not readily available.

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