LENSES
objective fore lenses

Middleton Research provides specifically designed, high quality fore lenses, optimized to produce uniform and high performance images in the broad spectral ranges covered by hyperspectral imaging systems. All of the lenses offered in this catalog employ broadband anti-reflective (AR) coatings to minimize stray light and glare. Lens adjustments are locked to withstand harsh operating environments. Hyperspectral lenses, in general, have very good chromatic corrections in the stated operating wavelength range.

Lenses are offered in standard and enhanced series. While the standard series lenses have minimal spatial distortion in the order of the camera pixels, the Enhanced Series lenses from Specim Ltd have, at most, sub-pixel distortion in both dimensions. The optical performance of the enhanced lenses is matched to the performance of the inner optics of the spectrographs. Therefore, when selecting a lens for a hyperspectral system, consider an enhanced series lens first, for best performance.

The following factors will determine lens selection: wavelength region, working distance and field of view, each of which is explained here in greater detail.

Wavelength Region

In order to obtain the best chromatic and spatial profiles, the lenses offered in this catalog are composed of a variety of different materials and contain multiple optical elements. Lens materials and coatings are optimized for specific wavelength regions. To determine the best lens to use, it is important to know the full spectral range of the specific application.

This catalog offers a wide array of lenses specific to particular UV, visible, VNIR, NIR, SWIR, MWIR and LWIR regions. Some of the lenses work effectively across more than one wavelength range. The UV lenses are useful from 200-410 nm. For the visible range, high magnification lenses are available. The VNIR range is a wider wavelength range than the visible, therefore special lenses are offered in this catalog for the VNIR region. There are also NIR lenses that are useful from 1000-1700 nm and SWIR lenses that are optimized for the 1000-2500 nm region. SWIR lenses can also be used for the NIR wavelength region because they are both spatially- and color-corrected for the entire region, although they are more complex and, therefore, more expensive than the NIR lenses. Additionally, a number of dedicated lenses are designed specifically for our MWIR and LWIR hyperspectral cameras.

Commercial video lenses are optimized for the visible range and are usually coated for maximum throughput in the visible range only. Even though they may transmit light in the NIR or SWIR ranges, commercial visible range video lenses produce a large spatial and chromatic distortion, rendering them ineffective in these ranges.

Working Distance

Working Distance (WD) is defined as the distance from the end of the camera lens to the object or area under surveillance. The minimum working distance is the shortest distance a lens can be placed to the sample to still obtain a sharp image. Sufficient working distance is necessary to manipulate or exchange the sample. Most hyperspectral lenses can be focused from infinity to the minimum focal distance, as defined in the lens data tables. Notable exceptions are the close-up lenses which can be focused in a narrow distance range. In this case, the working distance is defined as the range in which the limited focus adjustment creates a sharp image.

Field of View

The field of view is expressed in angles and defined as the size of the area to be imaged. The field of view is determined by the working distance, slit width, camera sensor size, and the focal length of the lens.

Calculation of Focal Length

Lenses in this catalog are listed according to their focal length. Simple formulas are shown below for calculating the optimum focal length lens from the working distance, the dimensions of the object, and the dimensions of the slit. Two dimensions of the object are used for determining the different parameters of the camera setup and lens selection. The length of the object determines the macro dimensions of the setup and lens selection. The width of the object, which is in the direction of the slit arrangement, can be used to determine the desired slit with. The slit width specifies how much of the sample is actually seen at any one frame of the push-broom

camera system. Please note that the slit width also determines the optical resolution achievable.
The following equations relate the known object size, desired resolution (length and width of the imaged line), and working distance to the required focal length and slit dimensions.

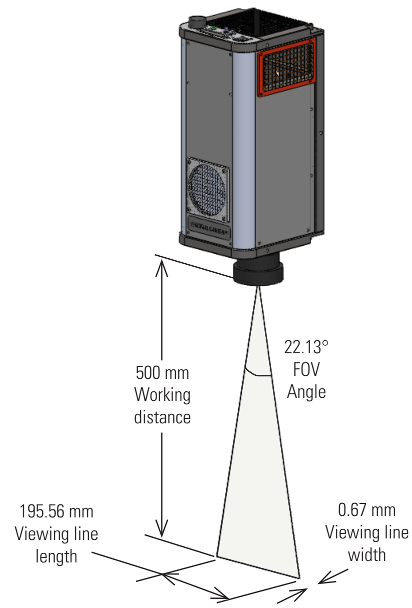
$$f = \frac{L_s D}{L_i} \quad or \quad f = \frac{W_s D}{W_i}$$

In the above equations, f = focal length of lens, D = working distance, L_s = length of slit, W_s = width of slit, L_i = length of imaged line, W_i = width of imaged line

Working distance is measured from the front of the lens to the viewed object; whereas, object to image distance is measured from the sensor to the object. To calculate the lens focal length required, the working distance must be used, not the image distance. An optical setup example is shown. Note that in this configuration, the object's width could be as large as 195.56 mm and, assuming a typical 30 µm slit in the camera, a 0.67 mm spatial resolution (width of viewing line) would be achievable.

A small table with examples of working distance vs. object size is included at the end of each lens specifications table to help identify and select the proper lens and mounting distance for different applications.

NOTE: For hyperspectral cameras, the lens must focus on the slit, and the slit width determines the width of the sample area viewed by the camera. The actual dimensions of the slit widths to be used for the calculations are noted in the camera and spectrograph chapters. In the slit length direction, however, the determining factor for the length of the image line is the sensor dimension, not the physical slit length, because the sensor is usually shorter than the slit. In the case of a 2/3" sensor, the slit length is limited to 8.8 mm, and this length should be used for the calculations. See the Glossary for further explanation.



Mounting

C-Mount is a standardized lens interface most commonly used by camera manufacturers. Most spectrographs and cameras in this catalog, therefore, offer C-Mount interface on the lens side to accommodate the large variety of commercially available lenses.

The focal distance from the camera side flange to the sensor is 17.526 mm. The standard threading for connecting the C-Mount lens to a camera or spectrograph is 1"-32UN2A.

While C-Mount is the most widely used standard mounting in the visible video industry, different mounting arrangements may be required due to larger sensor sizes, different wavelength ranges and other special features. For larger format cameras and for thermal cameras, special mounts are usually used and those are marked in the respective sections.

Telecentric Lenses

A telecentric lens is a special class of lenses having negligible or no distortion with the object being slightly above or below the focus. When using conventional lenses, the image size of an object changes depending on the location of the object relative to the lens focus. The lack of distortion is the result of the light collected from or projected parallel with the optical axis. Telecentric lenses are used extensively in machine vision metrology because the edges of objects must be seen in undistorted sharp focus so that dimensions of the object can be established from the image with a high degree of accuracy. In hyperspectral imaging, telecentricity is useful because some focal plane array cameras have micro-lens arrays that work best with the beam falling perpendicular to the FPA. Telecentric design is therefore a significant optical feature of the spectrographs offered in this catalog. Further explanation is found in the Glossary.

Lens Accessories

Spectral flattening filters can be attached to the lenses; for more details, refer to the filters section of the Accessories chapter.