THE COMPLETE GUIDE TO INDUSTRIAL CAMERA LENSES

Enhancing Imaging System Performance with The Right Lens

TELEDYNE LUMENERA
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TELEDYNE LUMENERA **WHITE PAPER**

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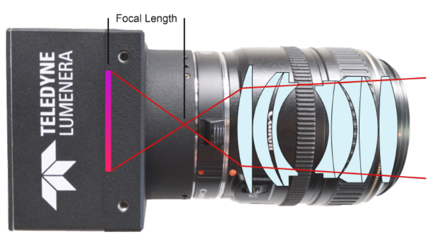

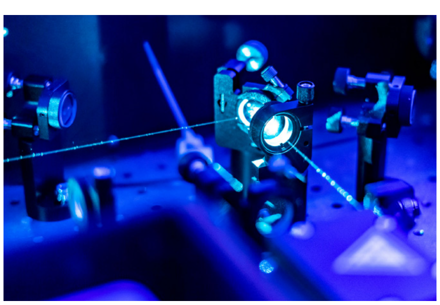

WHAT'S INSIDE

INTRODUCTION

A typical lens used with an industrial camera is actually a lens system made of multiple types of optical lenses within an enclosure. This type of camera lens is technically called a "compound lens." However, a camera lens is the colloquial term for a lens system when it is built with a mounting ring that can fit a variety of cameras. Choosing the correct camera lens for a vision system is critical for achieving a specific imaging result. This document will explore the physical attributes of a lens, the types of lenses and their unique optical characteristics, other considerations such as compatibility with different sized sensors, wide enough aperture, and effects of optical aberrations. Following this, applications that can benefit most from a lens choice will also be expanded upon at the end of the document. A variety of lenses used for cameras can be seen in Figure 1.

Figure 1 – Lenses in a variety of sizes and focal

PHYSICAL STRUCTURE

FOCAL LENGTH

Choosing the proper lens for an application needs careful consideration of its focal length. There are two main types of camera lenses, a prime lens and a zoom (also called varifocal / kit) lens. The key difference between these two types is that a prime lens has a fixed focal length, while a zoom lens has a range of focal lengths.

Focal length is the distance between the camera's sensor and where the light in the camera lens is focused, as shown by Figure 2. The focal length is often measured in millimetres (often abbreviated to mm) and provides plenty of information about what type of image will be captured, such as the angle of view (often referred to as the field of view or FoV) that the lens can capture and the magnification of the target within the image. For a mathematical approach to finding the perfect focal length based on an application's working distance, read the whitepaper, "Selecting a Lens for a Vision System."

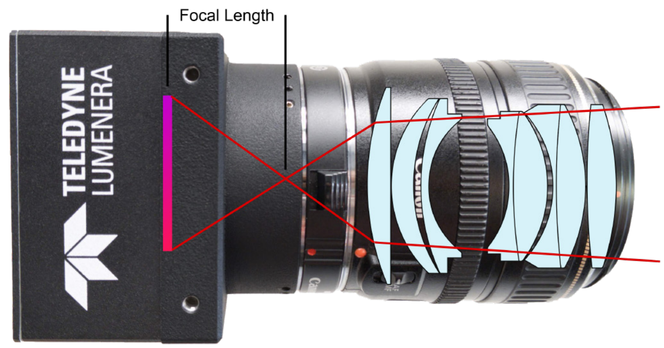

Figure 2 – Measuring focal length within a camera system

A normal focal length that does not greatly impact perspective is around 50mm. This represents a common perspective similar to that seen by the human eye. A typical zoom lens has a focal range of 35-70mm and provides a range of perspectives without stretching or zooming in on the subject too much. Even though this perspective is cropped down to a box frame due to the physical design of film and sensors, it is still the standard when it comes to how to capture a "normal" looking image.

Various types of lenses will be explored in this document to help provide a better understanding of what each lens type can accomplish, such as telephoto lenses for getting a more close up (or zoomed in) image and wide-angle lenses for their increased FoV.

THE FOCUS RING

Adjusting the focus of a camera lens manually, while it is in someone's hands, is referred to as pulling focus. This is common when an individual needs to adjust a camera position and refocus the lens. In commercial imaging applications, end users tend to connect industrial cameras to mounting equipment with a fixed position. When a camera is always pointed at the same target, a prime lens can allow for adjustment in focus during set up, or by autofocus use but does not have a zoom ring which would change the focal length. However, some applications that require moving components may need to refocus a camera at different focal lengths. In applications where a camera is moving, such as robotics or aerial imaging, it may be important to have the ability to focus at different focal lengths.

THE ZOOM RING

A zoom ring allows for the focal length of a camera to change. By increasing the focal length on the camera, the zoom ring actually narrows the FoV. This results in a close-up image, but with less of the surrounding environment in view. An example of this is demonstrated in Figure 3, where the more zoomed in the camera gets (the higher the focal length), the farther away the camera will focus and the narrower its FoV.

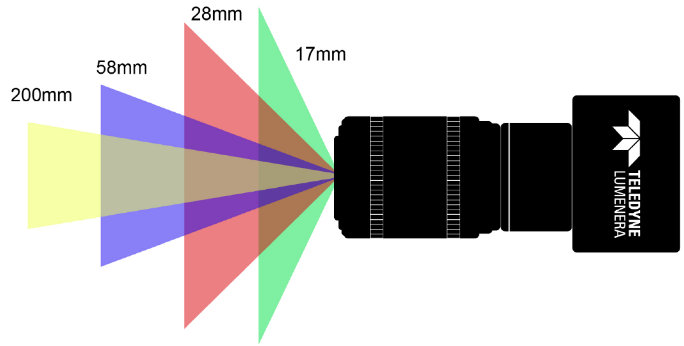

Figure 3 – Field of view changes to longer and narrower as the focal length increases

The amount of optics within a camera lens greatly varies on the type of lens. In general, a major factor is whether the lens is a zoom lens or a prime lens. A kit lens will have a larger number of lenses within the lens assembly because it needs to be able to adjust the focal point of the camera. Having a zoom ring also adds optics to the camera since it introduces more parts that need to adjust the light reaching the sensor. However, a prime lens is generally much simpler and has fewer parts. This often translates to a more affordable lens.

LENS MOUNTS

Before choosing a lens, a camera or sensor usually comes first. When choosing a camera for an application, understanding what type of lenses are available can be determined by the type of lens mount. Manufactures may use unique and sometimes proprietary mechanisms for securing a lens to the camera. The variety of lens mounts allows for a range of sensor sizes to be adapted within cameras. Since most lens mounts are designed to support a specific sensor size, when adjusting to a new lens it may be required that a compatible camera be used, or, for a more affordable solution, to use an adapter ring. These rings allow for the camera to use a lens mount that is normally incompatible with the camera. This opens a wide range of potential lens types and manufacturers that can be combined with the camera.

When integrating a lens with an adapter ring, some of the proprietary technology that a manufacturer may have implanted may no longer be compatible. This could result in losing a useful feature such as autofocus or the ability to adjust the aperture through the camera. However, if the industrial camera manufacturer provides OEM level integration, it may still be possible to integrate some functionality normally only attributed to the manufacturer of the lens. For example, Teledyne Lumenera can leverage the autofocus built into Canon EF lenses.

However, it is ideal to work with a lens that matches the sensor size of the camera to maximise the optical performance. Some common types of lens mounts include the A, E, EF, C, CS, and S-mount (also known as M12-mount). The C-mount and CS-mount lenses are most commonly used by Teledyne Lumenera for machine vision and industrial applications. The bottom line is that the type of lens mount that will be used in a given imaging application will vary based on the type of camera and any size restrictions.

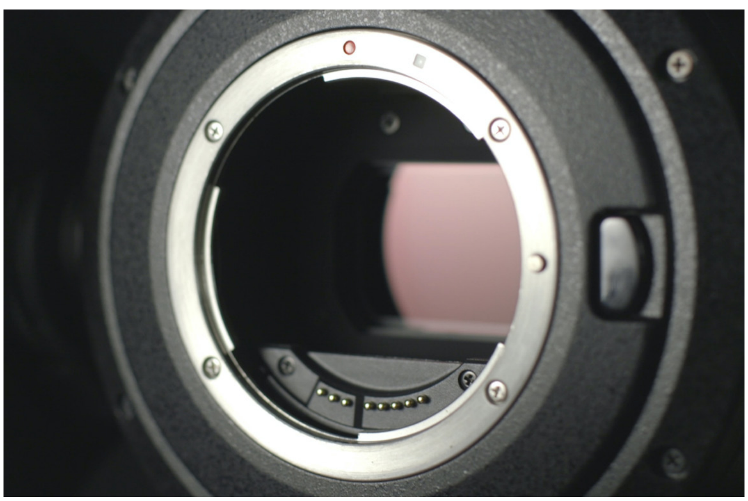

Figure 4 – Lens Mount for a Micro Four Thirds Sensor

LENS SHARPNESS

Industrial cameras with large sensors and high megapixel counts can produce very sharp images. The maximum resolution of a vision system is determined by the camera sensor. However, in order to produce these high-resolution images, a camera must be equipped with a lens that will optimize image quality.

The effective resolution of a vision system is limited by the camera lens. This is because imperfections in the glass can reduce image quality. From optical aberrations, to just having scratches or internal damage, light will be affected as it passes through the lens. The vast range of prices for lenses is significantly impacted all the levels of clarity that can be achieved. By adjusting for just one potential issue with the optics, or by improving the cleanliness of the manufacturing process and installing new checks for defects, each additional measure adds to the manufacturing costs of the lens.

With industrial imaging, camera lenses are often graded on sharpness based on lines pairs per millimeter. By identifying the narrowest pair of lines on a chart that are visually distinct, a level of resolution can be measured to represented how much detail can be imaged through a lens. For even more accurate measurements of image sharpness, software solutions also exist to analyze the result of imaging a specific chart, such as a USAF or Star Chart. An example of this can be seen in Figure 5 below where a pair of cameras image an ISO 12233 Image Quality Test Chart.

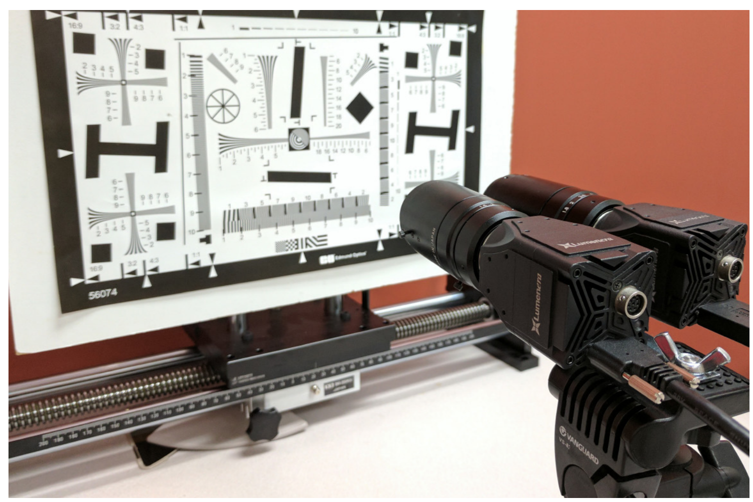

Figure 5 – ISO 12233 Image Quality Test Chart being imaged by multiple Teledyne Lumenera cameras

The exposure time and gain of the camera also greatly affects the sharpness. When the goal is to maximize resolution, the lighting and settings of the camera also play a significant role alongside the choice of lens. To learn more about how to properly configure a camera, see the Teledyne Lumenera blog post, "Configuring A Camera: How Exposure Time And Gain Impact Image Noise."

It is important to consider if a particular vision application actually requires very sharp details. When using high megapixel sensors, the benefit of using a high-quality lens can result in better effective resolution. Improving the clarity of an image can be done by using a larger sensor, even with a lower quality lens. This can be improved even further if the high-resolution sensor is equipped with a lens that is able to reproduce that kind of detail. Both sensor and lens resolution / sharpness are important for getting the most out of an image.

TYPES OF LENSES

There are several types of lenses, each of which represents a set of characteristics that produce a particular type of image. Looking at the appropriate category of lenses will provide a better selection for an application. This section covers lenses such as prime versus zoom, wide-angle, rectilinear and fisheye, telephoto, macro, and tilt-shift lenses. A variety of these lenses can be seen in the Figure 6.

Figure 6 – Set of prime and zoom lenses featuring different wide-angle and telephoto lenses

Prime versus Zoom Lens

There are two main types of lenses, prime lenses and zoom lenses. The main difference between these lenses is focal length. A prime lens is a fixed focal length lens, whereas a zoom lens has a focal length range that can be adjusted using a mechanism such as a ring that can be moved clockwise or counterclockwise. A comparison between a prime and zoom lens is shown below in Figure 7.

Figure 7 – Prime lens (left) and zoom lens (right)

For industrial applications, a camera is generally preforming a repetitive task during its use and is often fitted with a prime lens. However, for applications where the camera must image objects of varying distances, a zoom lens is installed.

Because it has fewer components, a prime lens is generally a more affordable option. This simplicity can result in better quality because with fewer variables there is a lesser chance of issues arising during the manufacturing process.

A zoom lens offers a greater degree of flexibility since they are capable of a range of focal lengths. To adjust focal lengths, a lens system normally has more optics and moving parts that can help converge light within the lens to different positions. This added complexity can add to the costs of a camera lens. The complexity in manufacturing a lens system with adjustable focal lengths can cause a reduction in clarity. Therefore, prime lenses are often considered more reliable for improved image quality if a variety of focal lengths is not required. However, lens technology has continued to improve over time and the gap between the quality of a prime and zoom lens has continued to narrow. This ensures that even under strict optical requirements for applications, it is usually safe to consider both prime and zoom lenses.

Wide-Angle Lens

A wide-angle lens gets its name from the wide viewing angle the lens provides. A pair of wide-angle lenses can be seen in Figure 8. In this image, the lens surface can be seen to curve much more than in longer focal length lenses. This exaggerated curvature allows light from wider angles to enter the lens and be redirected through the lens system to the sensor.

Figure 8 – Pair of wide-angle lenses

This type of lens is often the choice for imaging applications that require a top down view, such as with Intelligent Traffic Systems (ITS), and aerial imaging. In Figure 9, the left side depicts a traffic vision system imaging multiple lanes at once and on the right is an aerial imaging system used in precision agriculture to image a wide area of crops. A shorter focal length has a wider FoV, such as with a 17 or 28mm lens that can help the camera image more area at once.

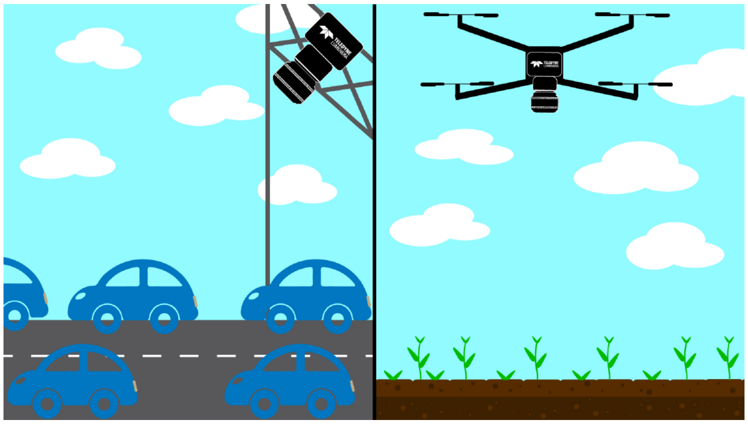

Figure 9 - Illustration of a wide-angle lens used to image an intelligent traffic system (left) and precision agriculture (right)

A challenge with using a wider FoV is the added distortion that comes with a wider image. There are more sophisticated / costly optics that correct distortion from wide-angle lenses. Using an image or video editing software can also adjust and compensate for distortion and can often produce images with a flatter FoV.

Rectilinear and Fisheye Lens

Figure 10 – Rectilinear lens (left) next to a fisheye lens (right)

The advantage of using a wide-angle lens is the added FoV. However, the barrel distortion that occurs can affect the results from image analysis. Rectilinear lenses are designed to eliminate this barrel distortion. Even with those lenses that still have a little distortion, this can normally be easily corrected in post-processing. With very wide angles, even a lens with optics designed to compensate for distortion will not have a perfectly flat FoV. However, modern lens technology mitigates these effects and so they are mostly negligible.

The opposite of a rectilinear lens is a fisheye which uses a very wide angle FoV but does not correct for distortion. Generally, a fisheye offers close to 180 degrees in the FoV, but will warp the image to have very round corners. It is possible to correct for distortion with image post-processing. However, this will often involve altering the edge of an image. Through stretching and shrinking, the image will end up losing clarity that would normally be there in the case of an optically corrected image where the lens is able to deliver a distortion-free image to the sensor. Alternatively, the image can be cropped to remove the distorted portion, but this removes any benefit of using such a wide FoV.

Telephoto Lens

Figure 11 – Set of telephoto lenses illustrating a longer focal length can be achieved in both small and large form factors

In the opposite spectrum, the telephoto lens narrows the FoV of the camera. Using a longer focal length such as 100 or 200mm, the camera can effectively focus on farther targets. This narrow FoV does not include the distortion that is often found within wide-angle lenses, but in lower quality lenses or at extremely long focal lengths, pincushion distortion can occur, bending inward the sides of an image. In Figure 12, a zoom telephoto lens can be seen fully extended next to a telephoto prime lens. The light entering a wide-angle lens needs to be squeezed to reach the sensor, whereas the light from the telephoto lens has a fairly direct path to the sensor.

Figure 12 – Two telephoto lenses: zoom lens (left), prime lens (right)

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Macro Lens

Figure 13 – Macro lens at 100mm focal length

A lens can only get so close to a target before it can no longer focus. A macro lens can range significantly in focal length (approximately 35 – 200mm, but not exclusively), but the optimal results are normally within the middle of that range. The reason for not wanting too short of a focal length comes from the reduction in light. By having a wider lens FoV, the camera will need to get closer to the subject, causing the camera to potentially block sunlight and cast a shadow on the subject. For focal lengths that are too long, the camera would need to be positioned at a further distance. This can be a problem when trying to focus on a small subject and the observer is forced to physically distance themselves due to the longer focal length. In the case of a very long focal length the camera will not be able to get close to the target and therefore it will end up reducing the magnification that the lens can provide.

The value in capturing a close-up macro image comes from the magnification it provides. A macro lens can provide at least a 1:1 magnification ratio which means the image captured by the sensor is proportional to the target's actual size. Some macro lenses can magnify an image more than the standard 1:1 ratio and this usually adds a steep increase in the price of the lens. However, when imaging details on smaller targets is crucial, then having a higher amount of magnification is necessary.

Minimum focus distance is another contributing factor to the value of a macro lens. For example, two lenses might each be capable of creating a macro image with the same magnification, but the camera that is able to focus at a reduced distance to the target is typically considered more valuable because the lens has a more flexible working distance. This means the lens with the better minimum focus distance is creating a longer depth of field (DoF). This can be seen in the Figure 14 below, where the yellow field represents the DoF.

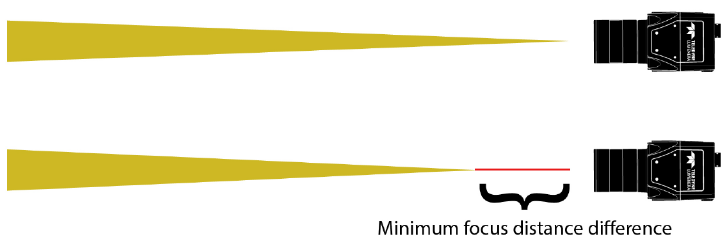

Figure 14 – Comparison of cameras and their minimum focus distance

Tilt-Shift Lens

Figure 15 – 24mm tilt-shift lens

A tilt-shift lens allows for the internal optics of the camera to move off the optical axis. This can be one of the more complex lens systems due to the shifting mechanism. In Figure 16, the top diagram represents a camera at ground level that is capturing an image of a building, but is not getting the full height in the frame. The middle diagram represents a camera at ground level that has a tilt-shift lens shifted upward to capture the full view of the building in frame while keeping the camera sensor parallel to the building. The benefit of using the tilt shift lens is the ability to not warp the perspective of vertical lines such as the structure of a building, this can be seen in the middle diagram with the building imaged without any perspective issues. The bottom diagram shows a camera tilted upward to capture the full building within the frame. However, the upward angle of the camera causes the angle of vertical lines to shift. This warping can be an issue when imaging large structures or when imaging from lower altitudes.

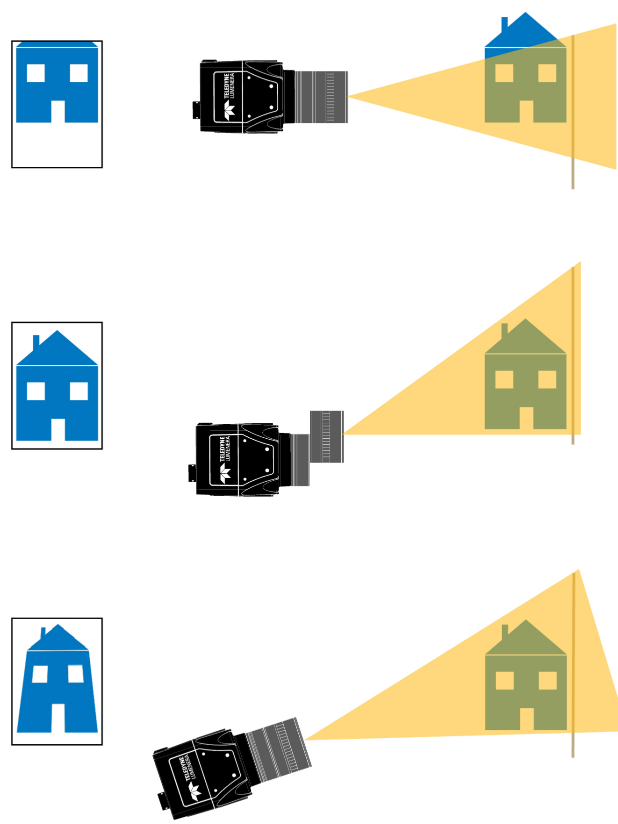

Figure 16 – Mechanism in a tilt-shift lens used to properly capture the vertical lines of a building

Another benefit of using a tilt-shift lens is the ability to capture an entire image in focus without having a smaller aperture. This can be achieved by tilting the lens so that the plane of focus is no longer just in front of the camera as it normally would be, but angled toward the ground so that the apparent DoF is stretched. Alternatively, the lens can shift the optics so that only one part of the image remains in focus. This partial or selective focus often ends up making targets within the image appear minimized.

As previously mentioned, the tilt-shift lens can fix distortions. This includes parallel vertical lines that would normally converge because of position of the camera sensor to the image plane. The tilt-shift lens allows the camera to stay parallel to the surface it is imaging without requiring the camera to be angled upwards or down to image a subject. A comparison between the distortion and the corrected vertical lines can be seen in Figure 16 with the corrected image in the middle and the image with the distorted vertical lines at the bottom. The tilt-shift lens itself can be angled, leaving the camera fixed in its position. Figure 17 shows the profile of an example tilt-shift lens. The base of the lens can remain in one position while the rest of the lens can be angled towards a target.

Figure 17 – Tilt-shift lens adjusted off axis

SENSOR SIZE

Choosing the right lens for an industrial camera requires understanding sensor compatibility. The various lens mounts that are described in this document are designed to work with specific sensors sizes. By matching the right lens to a sensor, a camera can capture a full image without any vignette. An example of a vignette can be seen in Figure 18 where a coffee cup is imaged, but the larger sensor is having a shadow cast from the lens that is designed for a smaller sensor size.

Figure 18 – Vignette on an image of a coffee cup

A camera's sensor size results in the camera's crop factor. By choosing a specific focal length and switching the camera to use different sensor sizes, the image will become more and more zoomed in as the sensor size is reduced. This can be seen in Figure 19 where a full frame 35 mm sensor represents the full-sized image, and this continues to become more zoomed in as the sensor size is reduced all the way to a ¼" sensor. By reducing sensor size, an image is applying a crop factor which is similar to how a lens can increase focal length to zoom in. Therefore, a smaller sensor will require either a wider FoV to capture the full target or will require that the camera is physically distanced until the full target is in frame.

Figure 19 – Set of images captured from the same focal length, but with different sensors to visualize the effects of crop factor

Figure 20 shows a variety of sensor sizes offered by Teledyne Imaging cameras. The largest sensor size represented is in the Teledyne DALSA Falcon4 camera that uses a medium format sensor. The smallest represented is in the Teledyne DALSA Genie Nano C / M640. This variety of sensors only begins to illustrate the number of possible lenses that can be used in various vision systems. Because each sensor type has a variety of compatible lenses, it is important to understand how much additional cost a lens may contribute to the overall vision system. A small sensor could be equipped with an affordable fixed focus lens that would normally range on the lower range due to the smaller and fewer moving parts. However, the price of a lens usually increases proportionally compared to the size of the sensor within the camera. For a medium format sensor, the resolution would be so high that the optics required would need to be a very high quality which greatly increases the cost of system.

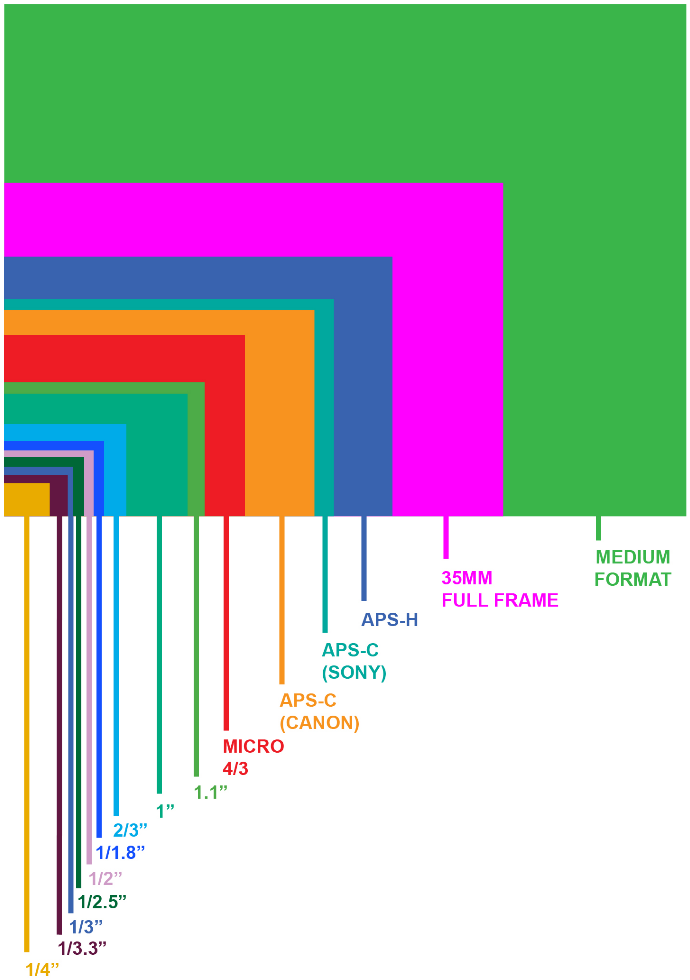

Figure 20 – Comparison of different sensor sizes

To learn more about the naming conventions behind different camera sensor sizes, read the Teledyne Lumenera's blog, "Why Sensor Size Matters When Selecting A Camera For An Imaging Application."

APERTURE

Depending on how much of an image needs to be in focus, the aperture may require adjustment. By opening the aperture more, the camera can provide more light to the sensor. However, this results in a shallower DoF that reduces the distance between the farthest and closest in-focus targets.

The opposite is also true, where a reduced aperture size creates a narrow hole for light to pass and increases the DoF allowing the camera to view more of the image in focus. Aperture is represented in f-stop values. An example of f-stops may be, F1.4, F2, F5.6, F11, F16, F22, with many other values possible. The f-stop value represents how closed or open the iris is within the lens. A higher value, such as F22 represents a small almost closed aperture, whereas a low value, such as F5 represents a large open aperture. A comparison between these apertures can be seen in Figure 21. To learn more about how aperture plays a key role in any imaging system, visit our blog on, "Improving Imaging System Performance With Lens Aperture Optimization."

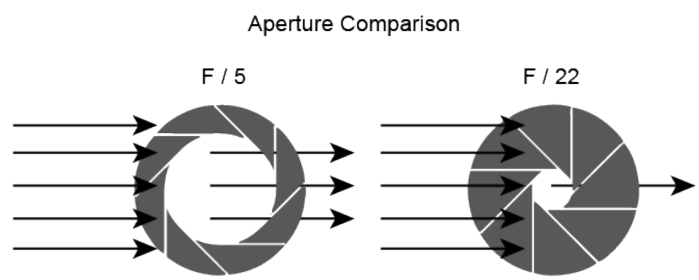

Figure 21 – Aperture comparison between a large aperture (left) and a small (more closed) aperture (right)

OPTICAL ABERRATIONS

There are several types of optical aberrations that can occur when imaging. When optics are not properly aligned, or certain steps are not taken to ensure the proper image, optical aberrations can result in various types of image issues. In some cases, optical aberrations are not a bad thing. In the case of a wide-angle lens, the added benefit of having a much wider FoV can be more significant than the aberration along the edges of the images.

Removing optical aberrations can be expensive. Building an ideal vision system with lenses that correct for all possible aberrations adds a lot to the cost. An example of a common aberration is barrel distortion (see Figure 22). A detailed list of optical aberrations, their effects, and how to mitigate them can be found in the blog post, "Six Optical Aberrations That Could Be Impacting Your Vision System."

Figure 22 – Barrel Distortion with white grid lines showing how the warping of the wide-angle lens is affecting the image

Spherical aberration is another common type of aberration and causes the edges of an image to blur. This is due to the spherical shape of most lens optics that causes light to focus at different points along the optical axis. This can be seen in Figure 23, where the bottom diagram shows the multiple points of focus due to spherical aberration and the top shows an aspherical lens fixing the aberration. To learn more about how spherical aberration affects images and ways to mitigate this, read the blog post, "Minimizing Spherical Aberration: Make The Right Lens Choice For Your Imaging System."

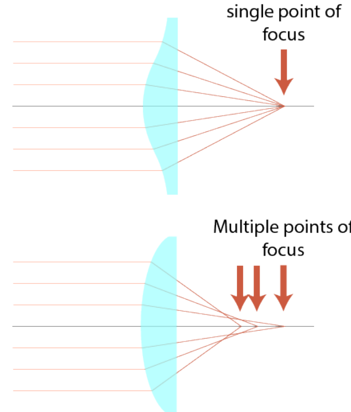

Figure 23 – Spherical aberration described with the multiple points of focus

APPLICATIONS FOR DIFFERENT LENSES

There are a wide variety of lenses on the market that each have a very specific usefulness depending on the specific imaging application. Factors such as aperture, focal length, and crop factor from sensor compatibility can impact the suitability of a lens to an application. Particularly for focal length, in the case of applications that require a wide FoV, a wide-angle lens is usually the typical choice. For other applications where the vision system itself and / or camera may be at a significant distance from the target, a telephoto lens may be the best choice.

Aerial Imaging

Aerial imaging is a unique application where many lens types can be a potential match. The key to choosing a lens for aerial imaging is understanding the ground sampling distance (GSD). GSD is directly related to the altitude of an aircraft with its vision system. However, in higher altitude applications, a longer focal length lens, such as a telephoto will likely be the best lens type. The telephoto lens' advantage is the ability to narrow in on the target subject and have a finer amount of detail on farther targets. Alternatively, for lower altitude imaging, it may be more appropriate to use a wide-angle lens such as a 17mm lens to better capture more of the environment without having to increase the cameras altitude. To learn more about GSD and how to calculate what type of lens is best for an aerial imaging system, see the blog post, "The Challenge Of Aerial Imaging: Achieving A Clear And Sharp Image."

A wide-angle lens is often useful for applications such as precision agriculture because it provides a wider FoV. This would be preferred to a telephoto lens that would need to waste more battery within a unmanned aerial vehicle (UAV) to fly to higher altitudes so that the lens could image the same area. In some cases, beyond using a wider lens, it may even be better to use multiple smaller cameras to increase the effective pixel width for the vision system, even more so than by just using a larger camera with a bigger sensor, as shown in Figure 24. To understand more about using multiple cameras in aerial imaging, read the Teledyne Lumenera white paper, "Using A Single Versus Multiple Cameras in Aerial Imaging."

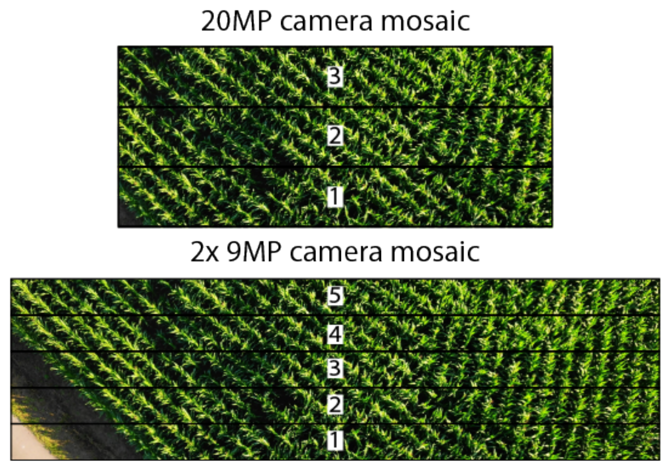

Figure 24 – Comparison in pixel width between a 20 MP camera and two 9 MP cameras

Laser Profiling

Laser profiling is an example of an imaging application where it may be more viable to use a camera without any lens at all. This is because the addition of glass, such as a camera lens, creates an issue of absorption and reflection.

In laser profiling, resolution is key because any change in the laser beam profile as it passes through the glass in a camera will give a false positive. The point of capturing the profile of a laser is to understand how evenly the light emitted from the source is distributed. Therefore, any chance for intensity or directionality of the light to change, as it would passing through a material (even glass), will cause the effective resolution of the image to reduce. To ensure an accurate image for laser profiling, it is important to consider cameras without any glass in the enclosure (including the thin sensor glass). It is in these cases where Teledyne Lumenera's Without Cover Glass (WOCG) ordering option on select camera models can provide value. To learn more about the WOCG ordering option, contact our imaging experts at lumenera.info@teledyne.com.

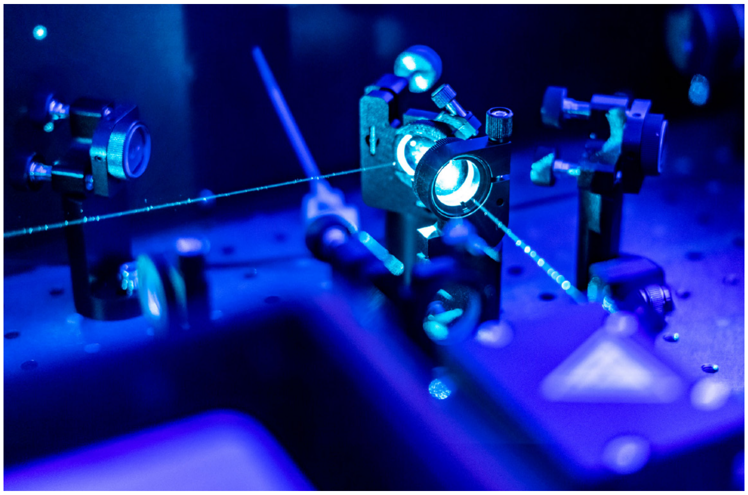

Figure 25 – Laser beam profiling

Surveillance

With surveillance and security applications, cameras are usually equipped with lower focal length wide-angle lenses. This enables capturing a wider FoV when monitoring an environment. If a narrower FoV is used, additional cameras would be required to substitute for the wide-angle lens' FoV. CS-mount lenses are often used in surveillance, although C-mount lenses may also be an option. C-mount lenses can also be adapted to work with CS-mount cameras to open up more imaging opportunities. However, the height of the camera must be considered since surveillance a higher altitude can create a challenge when trying to discern image data with a wider lens. In these circumstances it may be important to look at longer focal lengths to better zoom in on a subject of interest.

Figure 26 –C-mount Teledyne Lumenera Lt Series Camera with P-IRIS

P-IRIS lenses are also an important when considering the adaptability of a vision system for security. With a P-IRIS lens, a camera can adjust its aperture value with software. This can be a big help when a camera is placed in an environment with dynamic lighting, such as outside of a building where day and night light levels greatly affect the image quality. To understand more about the advantages of P-IRIS, read our blog post, "Why You Should Be Using A P-Iris Lens In Your Vision System."

Intelligent Traffic Systems (ITS)

For applications like traffic imaging that require cameras to be mounted high above the area being imaged (e.g. on posts or s gantries above a freeway), the elevation provides a great boost to the DoF. By using telephoto lenses on a freeway, a lens is capable of imaging more vehicles in a variety of distances. This option may limit the number of lanes a camera might be able to accurately image. In Figure 27, a comparison of a telephoto lens capturing multiple cars in a single lane versus a wide-angle lens which can capture multiple lanes at once. By changing to a lower aperture, a wide-angle lens may be able to capture even farther, or by using multiple cameras with longer focal lengths, a greater number of cars could be captured. The best choice of a lens will depend on several factors that includes, but is not limited to, the frame rate of the camera, environmental conditions, and how many lanes are available. Therefore, based on where the cameras will be deployed, a variety of focal lengths should be considered to find an optimal vision solution.

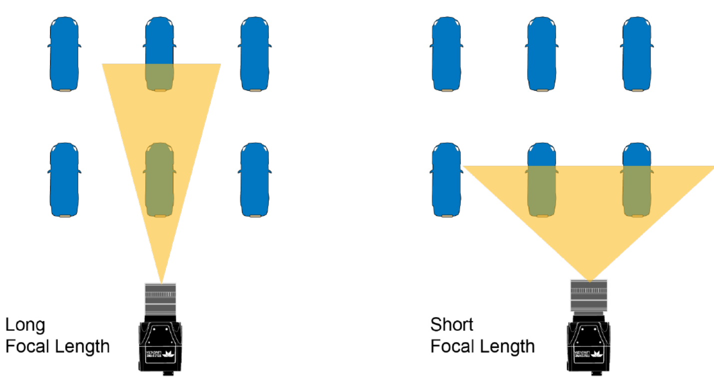

Figure 27 – Comparison between long focal length and short

WHICH LENS TO CHOOSE?

The lens is the first part of the vision system that affects the light being captured. It is critical to understand how a lens will impact the light as it is bent through the optics and where a particular focal length will provide the best perspective. The ideal lens for an application comes down to several factors including, the size of the sensor, the optical requirements of the system, and whether the physical construction even fits within the design parameters of the vision system. The conclusion is that the perfect lens does not exist. Rather, there are many lenses that better suit particular use cases. To get help with building the right vision system for any application, contact our imaging experts at lumenera.info@teledyne.com.