RUGGEDIZATION OF IMAGING LENSES

Imaging lenses used in many industrial machine vision applications have special requirements beyond those of standard imaging lenses. The lenses used in factory automation, robotics, and industrial inspection have to work in specific and demanding environments, which could involve vibrations, shocks, temperature changes, and contaminants. Because of these environmental requirements, new classes of ruggedized lenses are being designed specifically to work in a multitude of different scenarios, therefore creating different types of ruggedization. There are three distinct types of ruggedization available: Industrial Ruggedization, Ingress Protection Ruggedization, and Stability Ruggedization.

To better understand the distinguishing qualities of ruggedized lenses, standard fixed focal length lenses must first be defined. A standard imaging lens will typically be designed for an industrial camera with an F-mount, threaded C-mount, or similar mount. The lens will have a manual adjustment of focus, typically consisting of a threaded barrel within another threaded barrel, to allow for a smooth movement without rotating the optics. The focus will also typically have thumb screws to fix the focus position once the object in view is in focus. The iris will also be manually adjustable, often with ball detents, to set the adjustment into specific f-stops. ***Figure 1*** shows a standard fixed focal length lens with a double-threaded focus and multi-leaf iris with ball detents. The iris is made of many thin moving leaves that overlap and move together when adjusting the f-stop, as shown in ***Figure 2***.

Figure 1

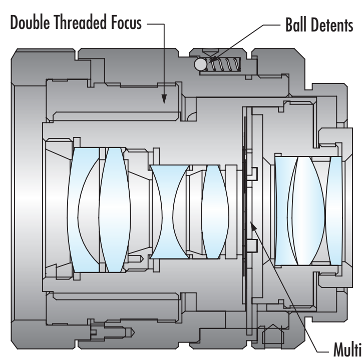

Figure 1: Standard imaging lens with complex mechanics and an adjustable iris

Figure 2

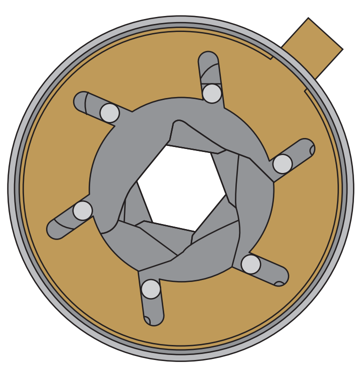

Figure 2: Standard iris with moving leaves

Industrial Ruggedization

There are many applications for Industrial Ruggedized lenses, such as high vibration factory environments, situations where the camera is rapidly accelerated and decelerated, inspection systems where many similar camera setups are repeated throughout a plant, and robotic vision applications. Industrial Ruggedization enables a lens to survive vibration and shock without damaging it or changing the focus. The main feature of this design is simplification - moving parts are reduced and made easier to lock down.

In this design, the iris is removed and replaced with a fixed aperture stop, eliminating many moving parts. Thin iris leaves can easily spring out of place and be damaged in a high shock or vibration environment; eliminating them is a simple change to greatly improve the survivability of the lens. The focus is also simplified: the non-rotating double threaded barrel is replaced with a simple single thread and a rigid locking mechanism, such as a clamp, nut, or several set screws. ***Figure 3*** shows an Industrial Ruggedized lens where the focus travel is reduced to a single focus thread with locking screws and the iris has been replaced with a fixed aperture. Vibrating machines and shocks from the lens moving on a robot or automated armature will not affect the focus or f-stop of an Industrial Ruggedized lens. These lenses also prevent the user from accidentally changing the setting when it is not intended.

Figure 3

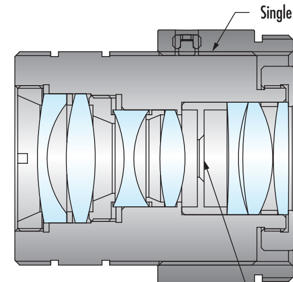

Figure 3: Industrial Ruggedized lens with simplified mechanics

Industrial Ruggedization is ideal for applications where the system will be set up once and not changed afterwards. An added cost advantage is also present in this type of lens due to the removal of the complex movements and adjustments, which results in a significant part reduction and cost savings.

The disadvantage to an Industrial Ruggedized lens as opposed to a standard lens is the lack of flexibility. Changing the f-stop is not a simple task and in most cases would require a different lens to be used. The focus travel will not be smooth and will rotate the optics while it focuses, which can cause a change in pointing in the lens (how an object point maps to an image point) as the focus is changed. Additionally, the locking method will typically make it more difficult to adjust focus and will likely require special tools, such as small hex drivers or large wrenches. However, in most industrial applications these disadvantages will not cause problems since standard lenses will likely be used to determine the setting for a machine. Once the machine setting is determined, an Industrial Ruggedized lens can be substituted into the application and set once to the appropriate focus and f-stop without being changed again.

Ingress Protection Ruggedization

The next type of ruggedization available is Ingress Protection Ruggedization. In this type of lens the assembly is sealed to prevent moisture or foreign debris from entering the lens. This retrofit is typically applied to a lens that already possesses features of an Industrial Ruggedized lens including a fixed iris and simplified focus, as the adjustments for f-stop and focus are often problematic for sealing. Sealing is typically done with O-ring and RTV silicone. This type of ruggedization is used primarily in applications where the environment has a great deal of humidity or moisture and space is not available to fully enclose the lens or camera for protection. Another application environment compatible for this type of lens is when spatter, dust, or small particles are present in the air around the lens. ***Figure 4*** shows an Ingress Protection Ruggedized lens sealed with an O-ring.

Figure 4

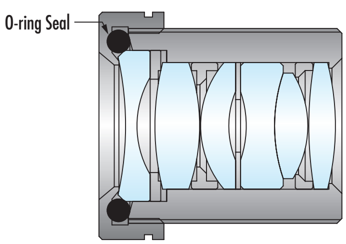

Figure 4: Ingress Protection Ruggedized lens with an O-ring to seal out contaminants

A disadvantage of this type of ruggedization is that only the lens is protected and further protection is required for the camera and the interface between the camera and lens. It is often simpler to use a single sealed enclosure that protects both the camera and lens together.

Stability Ruggedization

The final type of ruggedization is Stability Ruggedization, which protects the lens from being damaged and also maintains the optical pointing and positioning after vibrations and shocks. This is also an evolution of Industrial Ruggedization, featuring the same simplifications such as removing the iris and using a simpler focus. In addition, the individual lenses are glued into place to prevent them from moving within the housing. ***Figure 5*** shows a Stability Ruggedized lens in which the lens elements are glued in place and a clamping lock is used to simplify the focus.

Figure 5

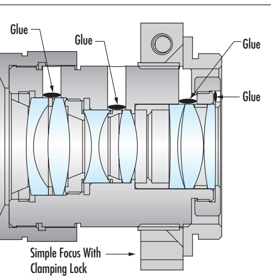

Figure 5: Stability Ruggedized lens with all elements glued in place

In an optical system, lens elements sit within the inner bore of the barrel. The space between the outer diameter of the lens and inner diameter of the barrel is minute (typically less than 50 microns). Despite the minimal amount of space, decenters of tens of microns are enough to significantly affect the pointing of the lens, see ***Figure 6.1, 6.2, and 6.3***. When using a Stability Ruggedized lens, if an object point is in the center of the field of view and falls on the exact center pixel, it will always fall there even if the lens has been heavily vibrated - stabilizing the image. Stability Ruggedization is important in applications where the field of view has to be calibrated, such as measurement equipment, 3D stereo vision, lenses used for sensing for robotics, and lenses used for tracking object locations. These applications often require the pointing to be stabilized to values much smaller than a single pixel.

The disadvantage of this type of ruggedization is the same as Industrial Ruggedization, which is a loss in flexibility compared to standard lenses. The additional design and engineering also adds cost compared to Industrial Ruggedization lenses since Stability Ruggedization lenses require more labor in assembly and glue the elements in place.

Figure 6.1

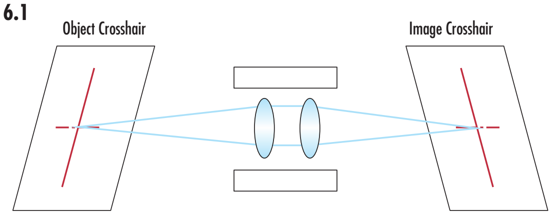

Figure 6.1: Unperturbed system where object crosshair is mapped to the image crosshair

Figure 6.2

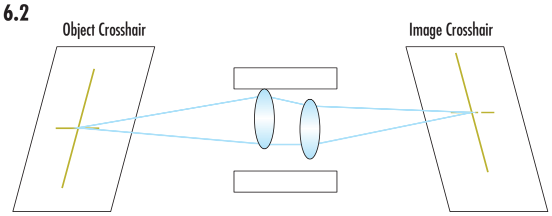

Figure 6.2: Perturbed system where lenses are decentered within the barrel and the optical pointing stability changes. Object crosshair is mapped to a different place on the image.

Figure 6.3

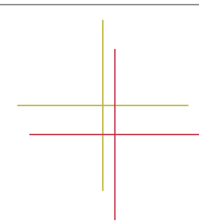

Figure 6.3: Image crosshairs overlayed, red crosshair is image from Figure 6.1 and the decentered yellow crosshair is from Figure 6.2. Example is highly exaggerated actual changes tend to be on the order of a pixel or less.

Conclusion

There are many options for ruggedizing machine vision lenses and no single option will work for every application. In order to determine the best ruggedized lens option, the application and its environment must be taken into consideration. As each ruggedized lens type features different but similar advantages and disadvantages, each factor should be reviewed for each application type. Knowing the best type of protection for your application will help extend the life of your system and provide the best performance and price.