TECH REPORT

VIDEO AUTOFOCUS

What Really Determines Focus Accuracy

Autofocus accuracy is one of the most frequently misunderstood topics in optical measurement – and for good reason: it's one of the most complex. In this paper, we will look at how video autofocus works, and what determines its accuracy.

1 OPTICAL BASICS

Good focus is vital for optical measurement. Since it is the image of a part, and not the part itself, that is measured, good focus is essential for good results.

First – let's look at how optical focus works.

To understand focus, start by thinking about an optical system we are all familiar with — the human eye.

The eye is a versatile optical system than can keep objects in good focus over long distances. A distant road sign can be in good focus at 100 yards or more. A newspaper is in focus when we hold it close, but not too close – typically about 10-inches away. In both cases, the sharpness of the image is a function of how far away the object is from the lens. An object anywhere within a certain range is in good focus. That range is our optical "depth of field."

One thing the eye cannot do is measure dimensions. When it comes to measurement, "good focus" is the distance at which the optics produce an image of accurate size. That distance is known as the Object Conjugate, or more commonly as the Focus Distance. Like the eye, the Focus Distance of optical measuring systems is actually a range, since the image will appear to be in good focus in more than one position. That range is the optical Depth of Field (DOF), and typically it is intentionally made small to ensure precise focus.

Figure 2: Optical Measuring System

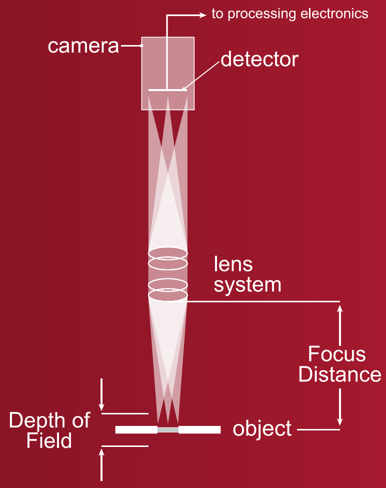
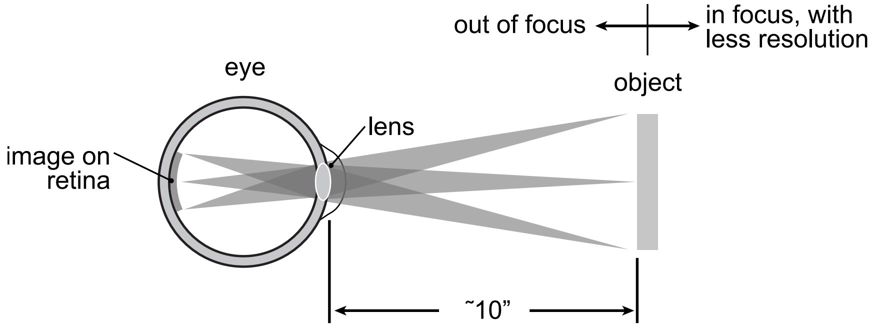


Figure 1: Human Eye Optical System



Depth of Field is determined by the Numerical Aperture (N.A.) of the optical design, which is represented by the cones of light in Figures 1 and 2. Some optical systems – like the human eye example – are designed to have long DOF so that many objects are in focus at the same time. This requires a small Numerical Aperture.

> **The OGP® SNAP™ and c-vision™ measurement systems are designed with low N.A. to achieve long DOF in order to minimize the need for focusing.**

Other optical arrangements, such as the camera example above, use a high N.A. to create a relatively shallow DOF, so that only the feature of interest is in focus. Confocal microscopes are an example of ultra-high N.A.

Incidentally, the optics in OGP Fusion™ systems have similar capabilities as SNAP, but also incorporate the high magnification and excellent autofocus capabilities of SmartScope systems. This gives Fusion systems the best capabilities of both worlds in long DOF and high N.A. measurement.

In optical measuring systems, the DOF is designed around the typical measurement systems the system will be used for.

The DOF, working distance and magnification range are matched to the part and feature sizes for convenient measurement.

Magnification and DOF are not directly proportional to one another, however as a general rule, the higher the magnification, the shorter the DOF, which is why it is recommended to focus using the highest magnification available on the system.

Many zoom lens systems, including Smartscope® systems, offer a choice of back tube, replacement lenses and attachment lenses. The selection of these elements can impact the DOF.

2 HOW DOES AUTO-FOCUS WORK?

To understand how Autofocus works, consider how you would manually focus a microscope, optical comparator, or video system. When we manually focus, we instinctively adjust the light level and focus to get a good, crisp image on the screen. Our eyes and brain process the image and intuitively make a judgment about when the edges in the image appear the sharpest.

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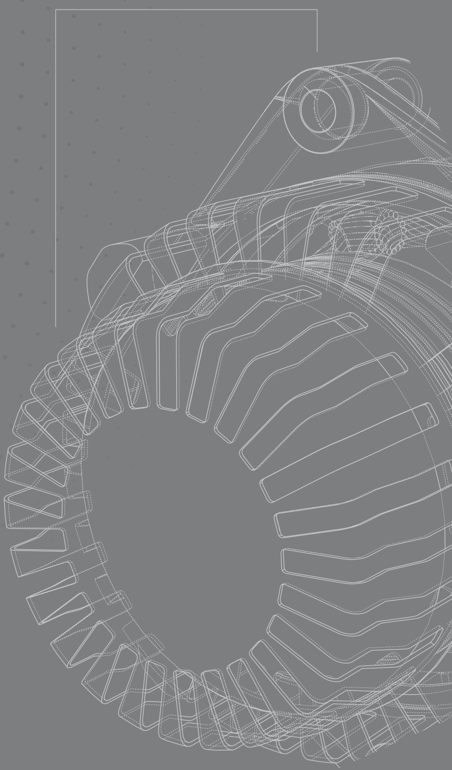
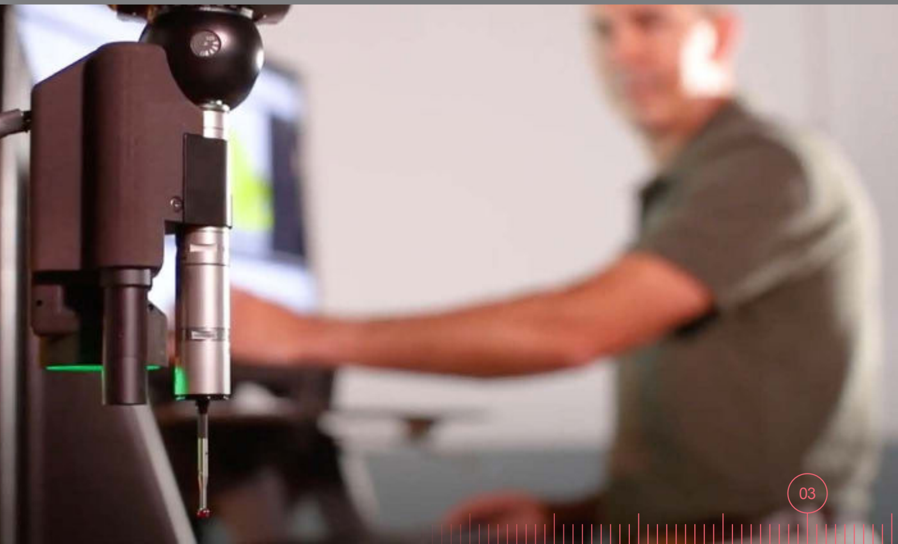


When we manually adjust focus, it is normal to start from an out-of-focus condition, and gradually move the image into focus, even going a little beyond best focus and coming back in order to confirm we have checked the whole range. When observing a feature in a microscope, if we step aside to let a colleague have a look, chances are they will immediately defocus the image, then re-focus it to suit their judgment of best focus. One thing is for sure – two people will rarely adjust the focus exactly the same way.

A video focus starts by backing off to de-focus the image, and then takes a series of small steps closer to the assumed position of best focus, taking video snapshots at each step to determine which step has the sharpest image contrast. The sharpness is continually measured at each focus step by examining the contrast across edges in the image.

The camera and computer process the edges in the image to find the position with the best contrast – just the way our eye and brain look for the best focus. The difference is that the computer determines the Autofocus position in exactly the same way every time, regardless of who operates the machine.

Autofocus works on exactly the same principles that we instinctively use when we manually focus.



3 HOW ACCURATE IS AUTOFOCUS?

Autofocus accuracy depends on several factors, but the primary factor is the optical DOF. Since the position with the best image contrast is within the DOF, we can say the focus accuracy is some fraction of the DOF. A conservative rule of thumb is that Autofocus accuracy is between 1/20th and 1/40th of the observable DOF. If the depth of field is 50 microns, 1/20th of that range would be 2.5 microns.

There are many factors that can impact Autofocus accuracy.
First, let's look at the way focus accuracy is specified:

Z axis accuracy is specified as:

$$E_1: (X.x + nL/1000)$$

For example: **E_1: (2.5+4L/1000) µm.**

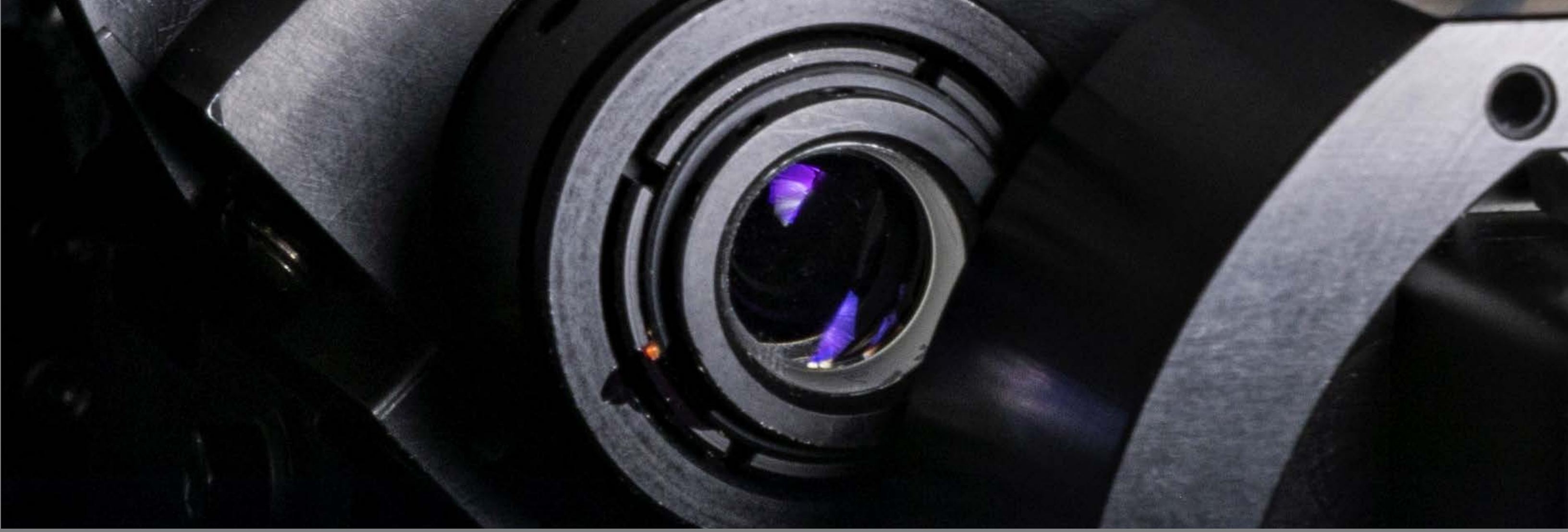
The first term – 2.5 in this example — is the constant. This figure is a good indication of the basic accuracy and repeatability of a focus measurement.

The second term – 4L/1000 – means add 4 times the length of measurement divided by 1,000 to the first term to determine the overall accuracy of a measurement between point A and point B. Given the short range of most Z axis measurements, the length dependent second term is not nearly as significant as it is for X,Y measurements. If we measured a height of 125 mm (5-inches), the Z axis accuracy would be **[2.5+(4*125/1000)] – or 3.0 microns.**

Verifying Z axis accuracy requires a standard that works well with Autofocus and covers the full range of focus travel with steps at several intervals.

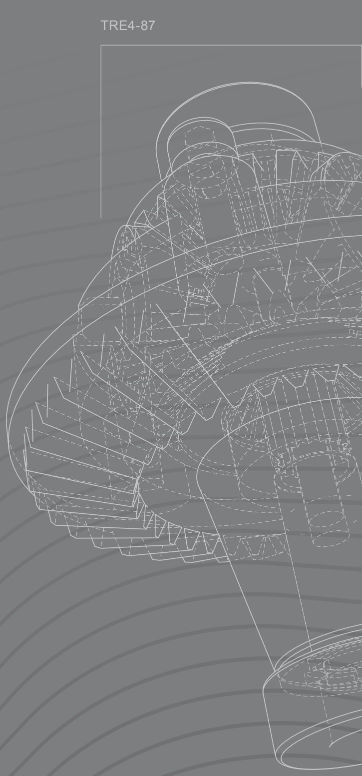
At OGP, we use master step gages having a series of six or eight steps with high contrast surfaces, spaced about 1-inch apart. Automatic routines in the calibration software perform Autofocus at each of these steps to determine focus accuracy. The step gage is a good standard for calibration and verification because it is a stable, durable, and repeatable master gage which can be easily certified and tests the entire Z axis measuring range in one set-up.

Linear accuracy specifications depend on more than just the Autofocus performance. E1: Z axis specifications account for all degrees of freedom in the Z axis, including focus and other normal variation.



4 WHAT CONTROLS DOES THE USER HAVE OVER AUTOFOCUS?

Video measuring software offers the user several controls to optimize focus performance. These settings can help get the best performance from Autofocus. Magnification is the first and most important control. Generally, it is recommended to focus at the highest magnification available, even if subsequent measurements.



Magnification is the first and most important control. Generally, it is recommended to focus at the highest magnification available, even if subsequent measurements are made at lower magnification. Zoom lens systems are generally par-focal, meaning that when an image is in focus at the highest magnification, it will be in good focus at all lower magnifications, so focusing at the highest mag ensures subsequent measurements are in focus, even if made at a lower magnification.

Focus Type is another user parameter that affects focus quality. Measure-X® and ZONE3® metrology software packages both allow users to set autofocus strategies in “Maximum Contrast”, “Top Down”, or “Bottom up” options. These can also be assigned run-time modes including “Fast Scan” to yield the fastest part routine runtime, “Optimize Scan” when parts are expected to vary greatly from sample to sample, and “Slow Scan” for the highest repeatability results.

Focus Area or tool size is an important variable that can be set for each focus step. The focus tool should be as large as practical to gather as much image information as possible, without overlapping any areas outside the plane of interest.

Many of the optical systems offered by OGP have the option of using a Grid Projector, which is a pattern of artificial contrast projected onto the part’s surface to enhance surface contrast. A Grid Projector is most helpful when a part’s surface is highly (mirror) polished, or is very dull with little or no contrast. Grid focus is very accurate because the grid pattern projects an optimum amount of edge information into the scene.

Focus Step Size is another parameter that can be optimized to fine-tune focus performance. Focus step size is set at the factory to synchronize with the camera frame rate. Each focus step must be synchronized with one frame or "snapshot" from the camera. The focus step size usually does not need to be changed from the factory setting, although at high magnifications, it is sometimes helpful to make a minor step size adjustment. Advanced metrology software usually allows step size to be set as a parameter in the Autofocus step, while other software use a global step size for each magnification level. This parameter should be used with care since it is possible to degrade focus performance with an incorrect setting.

Focus Back-Off Distance is another parameter that is sometimes used to fine tune focus repeatability. When there is more than usual variation from part to part, a longer backoff distance may be used to be sure the Autofocus process starts in a de-focused condition, and carries through the position of best focus. Again, some advanced metrology software allows the focus back-off distance to be set as a variable parameter in each focus step, while in other cases, the back-off is a global pre-set for each available magnification or objective lens on the system.

The most important variable in focus performance that the user can control is the light source and brightness. Focusing on a surface using top light provides much more edge information in the image to be used for focusing than focusing a single edge using back light. Focusing on a surface using top light is also generally more repeatable and more accurate for Z axis measurements. Oblique surface light can be used to focus on specific areas which may be angled with respect to the part's surface. Backlight is best for focusing on outside edges or at the bottom edge of a part.

> **Regardless which light source is used, setting the light intensity properly is key. Too little light may cause the focus step to abort due to lack of data. Too much light intensity can decrease the image contrast and makes Autofocus less repeatable. Setting the light level for maximum contrast – just as we would do for an X,Y measurement – is the key.**

Learn more about OGP Measurement Systems at **ogpnet.com**

OGP (Optical Gaging Products) is a division of Quality Vision International Inc (QVI®), a world leading manufacturer of precision multisensor metrology systems for industrial Quality Control. Our metrology systems focus on measurement technologies that help manufacturers monitor dimensional compliance to design specifications. First introduced in 1992, the famous OGP SmartScope® product family has become one of the world's most popular and versatile dimensional measurement systems. SmartScope systems are designed and produced at QVI corporate headquarters in Rochester, NY, USA. Flash branded systems are sold in North America while Flash CNC and CNC systems are found outside North America.

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