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# Auto Focus Performance –What can we expect from todays cameras?

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## Abstract

*The technology to let a camera automatically focus on the main object is more than 40 years old. We have a look at todays cameras and their auto focus performance. All tests are performed from the end-user perspective, so with final hardware and without access to the internal processing. With this information engineers get a better understanding on what to expect from todays cameras and how to design test procedures for system with auto focus systems. As an international standard is on its way, we also support the efforts of ISO with this work. We check for repeatability, accuracy and timing of the auto focus systems more than 300 camera systems and compare the different technologies behind it.*


## Introduction

Image Engineering operates a test lab for any kind of imaging systems. As the test time is critical for a commercial test lab, we evaluated what the best test procedure for a test of a camera-lens combination can be. In this paper we evaluated the measurement results of more than 320 camera/lens combinations. From this data, we derive conclusion how to optimize the measurement procedure.

To focus a camera system means that the focus distance and the object distance match each other. The object distance is the distance between the camera and the main object in front of the camera that shall be captured in the photograph. The focus distance is the distance between the camera and the plane of points in object space that are reproduced with the smallest possible circle of confusion. In manual focus (MF) the user manually modifies the lens while visually checking the focus distance. As soon as the intended object is in focus, the object appears with maximum spatial resolution in the image.

The automatic focus system (AF) in a camera system is supposed to detect the object distance and to adjusting the lens automatically to this distance. The AF system is a combination of detectors and actuators that manages to set the focus distance of a lens to the correct object distance.

We assume that an object is placed in front of a camera system. The object distance is defined by the physical distance between camera and object. The measurement of the object distance is based on passive or active measurement. In an active AF system, the distance is measured directly using e.g. Laser distance measurement or ultrasound methods using an independent measurement unit. This gathered information about the object distance is then used to control the actuators of the lens.

Passive systems do not measure the object distance directly, they use the imaging system itself of at least parts of it to define the object distance. The two major methods are phase detection and contrast detection. Combinations of these methods, so called hybrid systems, are in use in todays cameras as well.

### *Auto focus methods*

The pure contrast AF is a "trial and error" approach. The actuators of the lens are controlled that way, that the full range of possible object distances between infinity and closest focus distance is scanned through while the contrast at one or multiple locations in the image is measured and logged per focus position. If the object plane and the focus plane are equal, the point spread function (PSF) of all points on the focal plane is minimal, resulting in the highest spatial frequency response (SFR) and highest contrast. So after the scan, the actuators will set the lens to the position which resulted in the highest contrast. The contrast AF is performed using the actual imaging system as the focus detector. The AF system derives the information about the best focus position from the imaging system and controls the actuators accordingly. This system is potentially very accurate, as the focus position is optimized with the imaging system, so no calibration of the AF system to imaging system is required.

Originated from analogue single lens reflex (SLR) cameras, the phase AF is based on dedicated AF sensors that work through-the-lens (TTL). An additional system of lenses and mirrors behind the semitransparent main mirror are used to detect the phase shift between object plane and focus plane. That means that the AF system can measure if the current lens position is resulting in a front focus (focus plane too close to camera compared to object plane) or in a back focus (focus plane behind object plane) plus the information how far the lens is out of focus. So all information about the required correction of the lens position is calculated and then applied to the lens actuators. Other than the contrast AF the distance is actually measured and then the actuators are controlled. This system is potentially faster, as it does not require to check all possible distances first.

Even though the original Phase-AF requires dedicated AF sensors, the same term is also used in todays camera systems using dedicated pixel integrated into the imaging sensor. These pixel are masked in a way, that the AF system can derive information about the current lens position and the needed correction. In most cases the additional information from the Phase-AF pixel are used to accelerate the Contrast-AF as the range of distances that need to be checked can be reduced. That way the benefits from both methods shall be combined (accuracy from contrast AF and speed from phase AF).

## Repeatability and Accuracy

The focus has direct influence on the resolution. Any variation of the AF system will result in variations of a resolution measurement. So we can measure the performance of an AF system with a resolution test procedure. Additionally resolution measurement requires the best possible focus. We check for repeatability and accuracy of the AF systems based on a resolution measurement.

### Repeatability

Ideally the actions taken by an AF system are only depending on the object distance. So for a fixed object distance, the AF system should work in exactly the same way for multiple images. We define the repeatability of an AF system as the variability of the applied focus distance in the lens. This might be caused by variations in the object distance detection or in variations of the actuators to control the lens positioning. Without access to the internal positioning data, it is not possible to differentiate between these variations. As we do not have access to this information, we check the AF repeatability indirectly via a measurement of the spatial frequency response (SFR). Any variation of the AF system will result in variation of the SFR.

### Accuracy

We assume that the correct focus position leads to the highest spatial resolution of the camera system under test for the given object distance. So the better the AF accuracy, the higher the limiting resolution. Limiting resolution is defined as the MTF10 value, so the highest spatial frequency the camera/lens combination can reproduce with a spatial frequency response of 10%.

### Measurement procedure

The camera system under test has to reproduce a resolution measurement test target as shown in figure 1. The chart is illuminated with D50 daylight with 1000lux. The device is fixed on a tripod with a distance between chart and camera selected that way, that the chart height (81cm) matches the image height. To avoid negative influence from vibrations caused by user interaction with thecamera or the mirror (if part of the system), the camera is operated with self-timer and mirror lock-up.

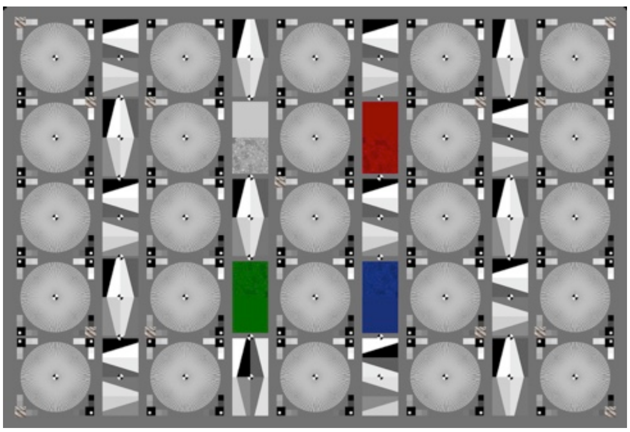


*Figure 1. The test target used for the resolution measurement. Using the S-SFR method defined in ISO12233:2014, based on a sinusoidal Siemens star. The complete chart featuring 25 siemens stars. Measurement performed on center star.*

Two test sequences are performed on each device under test:

AF This is the measurement of the AF performance. The operator will capture 10 images per measurement condition using the AF system to focus the lens. Before capturing an image the camera has to focus on a close object (hand in front of lens) following the focus and capture procedure.

MF This is the reference measurement to define the ideal focus position. The AF system is deactivated, the operator captures a sequence of images while manually focussing. If available, focus assistance of the camera system is used (live-view, enlarged details). From this sequence (at least ten images, more if operator decides to need more to be confident) the best image is selected. ”Best” is defined as highest limiting resolution in the image center.

All image quality related parameter are set to the factory default, the images are stored in 8bit JPEG, the aperture is fully opened.

For all images, the limiting resolution (MTF10) in the image center is calculated based on the algorithm described as S-SFR in ISO12233:2014[1] and other publications[6]. The method is based on a sinusoidal siemens star as shown in figure 2. The camera under test reproduces the test pattern and creates an image. A software solution reads the image and registers the different parts of the test target. The gray patches surrounding the star are used for linearization and normalization [3], the centermark is detected as a starting point for the analysis process. From the outer border of the star to the center, the digital values of the image are read out from a circle with changing radius. The spatial frequency can be directly calculated with the knowledge of the number of line pairs of the siemens star (here: 144) and the radius. The modulation is calculated from a harmonic function fitted to the digital values. This way, an SFR is obtained that is much more robust against sharpening and other image enhancement algorithms and is a very useful tool to measure the limiting resolution[2] of a camera system if RAW data is not available.

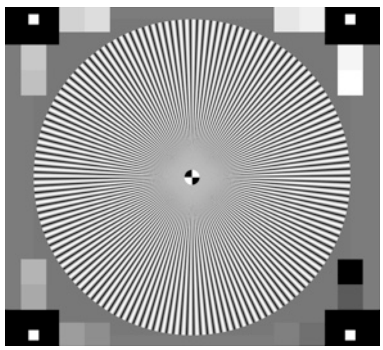


*Figure 2. The test target used for the resolution measurement. Using the S-SFR method defined in ISO12233:2014, based on a sinusoidal Siemens star.Detail: The single sinusoidal siemens star as defined in the standard.*

### Results

The main target was to find out if both the MF and AF sequence are needed and how many images we would have to capture if we use the AF sequence only and still want to get meaningful results about the limiting resolution. All results are derived from the S-SFR measurement using the MTF10 value as limiting resolution. We evaluated 320 different camera/lens combinations, 168 prime lenses and 152 zoom lenses. A camera/lens combination can be a D-SLR or system camera with interchangeable lenses or a compact camera system with build in lens. The zoom lenses where tested with three different focal lengths. The shortest focal length (W), the longest focal length (T) and one in between (S), defined as the average focal length of W and T.

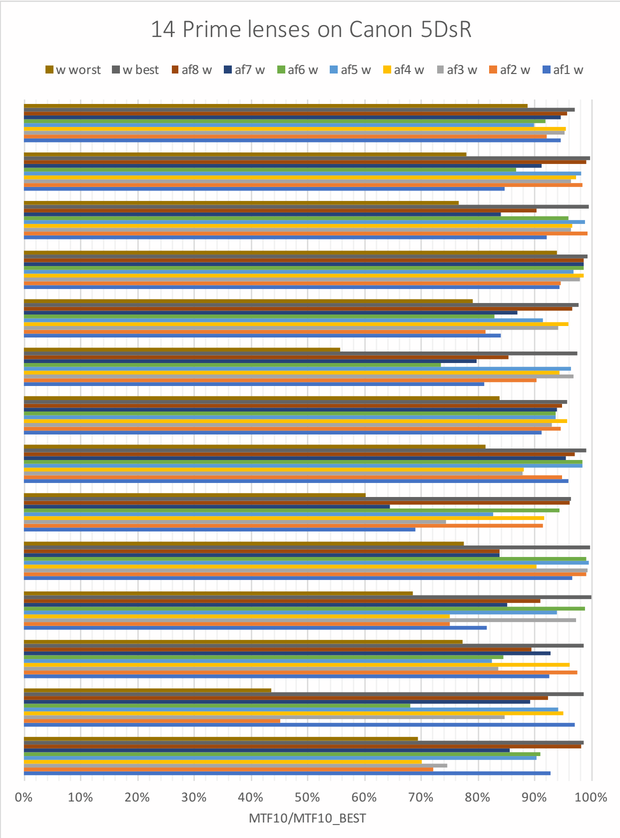
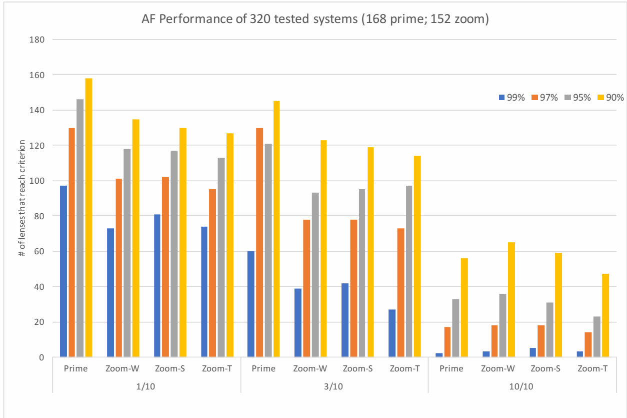



*Figure 3. AF Accuracy and Repeatability - Example of 14 prime lenses tested on a Canon 5DsR D-SLR camera. Each cluster shows the 10 images from the AF sequence, showing the limiting resolution in percentage of the best image (best from AF and MF sequence). We see devices with different repeatability (more or less variation) and that many of these devices do not have a single image that reaches to 100%.*

We checked the 10 images from the AF sequence and compared to the best image from the AF and MF sequence. "Best" is defined as the image with the highest limiting resolution in the image center.

In figure 3 we show a small subset of all acquired data. The graph show the results of 14 prime lenses tested on a Canon 5DsR D-SLR camera. Each cluster represents one lens, per cluster we see ten measurements of the AF accuracy. The AF accuracy is defined as the ratio of the measured limiting resolution to the best limiting resolution measured within the AF and MF sequence. In most cases, the MF sequence provide the best result, therefore only a few devices reach 100% at all. The repeatability can be observed as variation between the ten measurements per lens.

$$
\begin{aligned}
AF_{Accuracy} &= \frac{MTF10_{sample}}{MTF10_{best}} \\
&\quad with \\
MTF10_{sample} &= \text{MTF10 per image} \\
MTF10_{best} &= \text{max. MTF10 of AF and MF sequence}
\end{aligned}
\tag{1}
$$




| Criterion | Absolute | | | | | Relative | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 99% | 97% | 95% | 90% | | 99% | 97% | 95% | 90% |
| 1/10 | Prime | 97 | 130 | 146 | 158 | Prime | 58% | 77% | 87% | 94% |
| | Zoom-W | 73 | 101 | 118 | 135 | Zoom-W | 48% | 66% | 78% | 89% |
| | Zoom-S | 81 | 102 | 117 | 130 | Zoom-S | 53% | 67% | 77% | 86% |
| | Zoom-T | 74 | 95 | 113 | 127 | Zoom-T | 49% | 63% | 74% | 84% |
| 3/10 | Prime | 60 | 130 | 121 | 145 | Prime | 36% | 77% | 72% | 86% |
| | Zoom-W | 39 | 78 | 93 | 123 | Zoom-W | 26% | 51% | 61% | 81% |
| | Zoom-S | 42 | 78 | 95 | 119 | Zoom-S | 28% | 51% | 63% | 78% |
| | Zoom-T | 27 | 73 | 97 | 114 | Zoom-T | 18% | 48% | 64% | 75% |
| 10/10 | Prime | 2 | 17 | 33 | 56 | Prime | 1% | 10% | 20% | 33% |
| | Zoom-W | 3 | 18 | 36 | 65 | Zoom-W | 2% | 12% | 24% | 43% |
| | Zoom-S | 5 | 18 | 31 | 59 | Zoom-S | 3% | 12% | 20% | 39% |
| | Zoom-T | 3 | 14 | 23 | 47 | Zoom-T | 2% | 9% | 15% | 31% |

*Figure 4. AF Accuracy and Repeatability - Test on 320 camera/lens combinations, 168 prime lenses and 152 zoom lenses. We evaluated how many camera reach a certain criterion based on the limiting resolution (MTF10). It is evaluatd how many devices produce at least 1 out of 10, , 3 out of 10 or 10 of of 10 images within 99%, 97%, 95% or 90% of the maximum resolution. **top:** Graphical representation of the absolute values. **bottom:** numerical values: absolute - Number of lenses that reach the criterion. relative - Number of lenses that reach the criterion devided by devices under test.*

We evaluated for the prime lenses and for the zoom lenses how many lenses meet a certain criterion. For zoom lenses we checked for three different focal length settings (W,S,T).

The criterion is always a combination of the amount of images out of 10 that achieve at least X% of the best limiting resolution. The results are shown in figure 4.

Only 2 out of 168 prime lenses showed that high accuracy and repeatability that 10 out of 10 images showed a limiting resolution of 99% or better compared to the best image. Only 31% of the zoom lenses focussed that well, that 10 out of 10 images where in a range of 90% or better compared to the best image. Even if we would allow such high error of 10% for the limiting resolution, we see that we can not rely on a single image for the test of the limiting resolution.

The question would be, if it is o.k. to capture only 4 instead of 10 images. So in this case, we would have to find at least 3 images out of 10 that are acceptable close to the best image. In position T, less than half of all zoom lenses (48%) focus that well, that at least 3 out of 10 images reach 97% of the best limiting resolution. Increasing the acceptable error to 10% still means, that 25% of the zoom lenses would not reach this criterion.

As we have seen that it is not sufficient to capture a single image or to select the best out of 4, we want to check if we can get the best limiting resolution out of 10 images. Even when we accept an error of 10%, for only 84% of the zoom lenses the best out of 10 images captured with the auto focus would lead to an acceptable result. As we think an error of 10% is too high, we lower the acceptable error for our lab to 3%. That means that more than one third of the zoom lenses and more than 20% of the prime lenses do not give the best limiting resolution in a sequence of 10 images captured using the AF system.

We concluded from these results, that we have to keep the workflow to test all lens/camera combination with the MF sequence and that the AF sequence for a meaningful evaluation of the SFR, the limiting resolution and the AF performance.

| | μ | σ |
|---|---|---|
| all | 90,9% | 4,5% |
| D-SLR | 88,7% | 5,9% |
| System | 94,9% | 2,1% |
| Compact | 94,7% | 1,9% |

***Figure 5.*** *AF Accuracy and Repeatability - The performance for different types of systems for prime and shortest focal lenght of zoom lenses. Average ($\mu$) of the limiting resolution in AF sequence, relative to the best image. Average over devices of standard deviation ($\sigma$) per AF sequence in percent points.*

We classified the tested devices into three categories. ”D-SLR” are all cameras that use a mirror. ”System” is defined a cameras without a mirror but with interchangeable lenses, ”Compact” cameras have a fixed lens. Figure 5 shows the differences in accuracy and repeatability. We compared over all type of lenses, while we only used the shortest focal length for zoom lenses. The average of the AF accuracy over all measurements of the AF sequence is reported as $\mu$. We see that system and compact cameras show a higher accuracy. While compact cameras provide in broad average nearly 95% AF accuracy, D-SLRs provide less than 89% AF accuracy.

The repeatability is expressed as $\sigma$, the average of the standard deviation of the relative limiting resolution per AF sequence. It is expressed in percent points. We see that the D-SLR cameras have a significantly higher standard deviation over all tested AF sequences.

The observed higher accuracy and higher repeatability of compact and system cameras matches the general experience with these cameras. Even though the used dataset for this evaluation is very large, it was not sorted to match the distribution of focal length and largest aperture of all lenses per type of camera. So the general tendency remains valid, but the exact difference might be biased.

## AF speed

Next to the accuracy and repeatability of an AF system, the timing is an important factor of the user experience. A slow AF system can be a big annoyance for the user, especially when using the camera to capture rapidly changing situations.

### *Measurement procedure*

The measurement procedure for the AF speed is based on ISO15781[4]. This standard describes the measurement of shooting time lag and the shutter release time lag. While the first one includes the time the camera needs to focus onto an object, the second measurement excluded the AF. So the difference of the shooting time lag and the shutter release time lag is the AF speed.

***Figure 6.*** *The AF speed measurement setup. A mechanical finger is synchronized with a timing device. As soon as the operator activates the process, the release button of the camera is pressed and the timing device starts at the same time. The delay between pressing the release button and capturing the image can be checked in the captured image.*

The used setup is shown in figure 6. The device under test is mounted on a tripod and a mechanical finger is positioned on top of the release button. The finger is synchronized with a LED based timing device. With a defined frequency, the device will switch on one out of 100 LEDs at a time. So when the trigger signal from the mechanical finger is sent, the LED panel will start to ”run”, which means that it will illuminate one LED after another.

The trigger signal is sent as soon as the mechanical finger presses the release button. That way the time between pressing the release button and the start of the exposure can be read out from the image of the LED panel that the camera produced. The slower the camera, the higher the number of LED that is illuminated in the image. For example: The LED panel is set to 100Hz and we see in the image that the LED number 23 is the first one illuminated. We can no follow, that the device needed $23 \times \frac{1}{100Hz} = 0.23s$ to capture the image after pressing the release button.

The camera under test is pointed onto a test target with many edges in different contrasts, so we make sure the AF system can easily find a structure to focus on. In our tests, the chart is illuminated with D50 fluorescent light (300lux on chart). The distance of camera to chart is depending on the focal length of the camera under test and adjusted accordingly. With a chart height of 80cm, the distance is roughly 40 times the focal length (equivalent to 35mm film).

To measure the shooting time lag, the device under test is first defocused and then pointed onto the chart with the LED panel in the field of view. To measure the shutter release time lag, the AF system of the device under test is either turned off or in case this is not possible the device is pre-focused onto the chart. Both measurements (shutter release time lag and shooting time lag) are performed 10 times, the average is reported.

As the shooting time lag is the combination of AF speed and shutter release time lag, the difference of these two measurement equals the AF speed.

### Results

The AF speed has been evaluated for all devices that have also been analyzed for the accuracy and repeatability test. We show the results for two cameras. The Panasonic GX8 (Fig.8) is a MicroFourThird system camera, the graph shows 18 tested lenses. The Nikon D800 (Fig.7) is a full-frame D-SLR, we tested 28 lenses on this camera. The lenses are prime lenses and zoom lenses, for zoom lenses only the time for the shortest focal length (W) is reported. We see the general tendency that the system camera is faster compared to the D-SLR. Due to the two times larger sensor, the required mechanical movement of lens elements for the D800 is larger, it is harder for the device to achieve very fast AF speed.

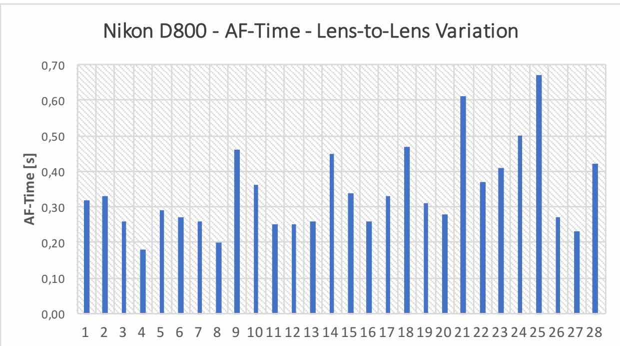



***Figure 7.*** *The measured AF time of two cameras with several different lenses to illustrate the dependency of the AF time from the used lens. Nikon D800 (D-SLR, Full-Frame Sensor) with 28 different lenses.*

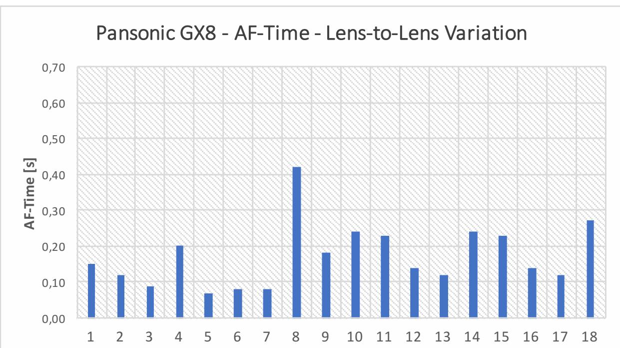



***Figure 8.*** *The measured AF time of two cameras with several different lenses to illustrate the dependency of the AF time from the used lens. Panasonic GX8 (System camera, MFT Sensor) with 18 different lenses.*

From checking this data, it is very obvious that even though the AF system is part of the camera, the lens has a significant influence on the measured AF speed. The factor between the fastest and the slowest lens is 6.0 for the Panasonic GX8 and 3.7 for the Nikon D800. So to get a fair comparison of two cameras, it is important to also make a fair choice on the used lens for the test.

## Tracking

A modern AF system is not limited to focus on a static scene, but shall be able to track a moving object. The use case would be to capture images of a person walking or running towards the camera. To test the tracking capabilities of a device, we assume that the device should be able to modify the focus position onto a moving test target which allows us to measure the resolution. The variation of the measured resolution should be low between images captured of the moving test chart.

### Measurement procedure

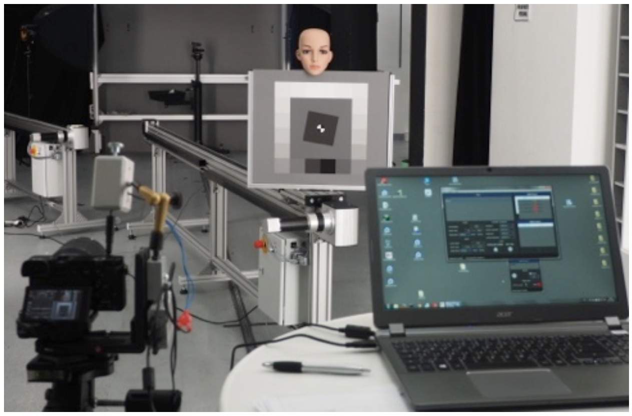


***Figure 9.*** *AF Tracking measurement setup. The DUT on the left, pointing at the test target mounted on a moving stage. The track lenght of the stage is 3m, resulting in a maximum distance of 5m and a minimum distance of 2m. The chart moves diagonal to the optical axes. An artificial face is mounted on top of the chart, the measurement is performed on the slanted edges of the test chart. A mechanical finger released the camera, synchronized with the moving stage.*

The test setup is shown in figure 9. The device under test is mounted on a tripod, facing toward a moving stage. On the stage, a test target featuring slanted edges (for the resolution measurement) and an artificial human face is mounted. The chart can be moved within a range of 3m, the complete stage is positioned in 2m distance from the camera. That way, the object (test chart) can be moved within a range of 5m to 2m distance between chart and camera. See figure 10 for an example of images captured at minimum and maximum distance. The speed of the movement is constant and freely selectable in up to 3m/s. For the published results in the following section we used a speed of 0.4m/s (a walking person) and 1m/s (a running person).

The chart contains a tilted square, which allows us to measure four slanted edges according to the e-SFR method described in ISO12233:2014[1]. The e-SFR method is based on the reproduction of a slanted edge. The first and most important analysis step is to generate an oversampled representation of the edge spread function (ESF). The oversampling is achieved by a binning process that is enabled due to the projection of all pixel within the ROI along of the slanted edge to build the ESF. The first derivative of the ESF is the line spread function (LSF) and the Fourier transformation of the LSF gives the SFR. The benefit of the e-SFR method is that it is very flexible for the chart requirement. As we have different reproduction scales throughout the test, a flexible chart solution is required. The e-SFR method is much more influenced by image enhancement algorithms, this can make it difficult to derive a limiting resolution from the e-SFR. As we are mainly interested in differences of the SFR, we choose to use the MTF50 value for comparison and measurement. The MTF50 value is the spatial frequency that leads to a SFR of 50%.

As the chart moved during the exposure time, the presented results are based on the analysis of the top and bottom slanted edge on the chart, as these are less influenced by motion blur. That way we reduce the influence of the exposure time onto the results. We calculate the average SFR of both edges and from this SFR we derive the MTF50 value. The whole measurement has been performed on the camera JPEG images with default settings for all image quality parameter.

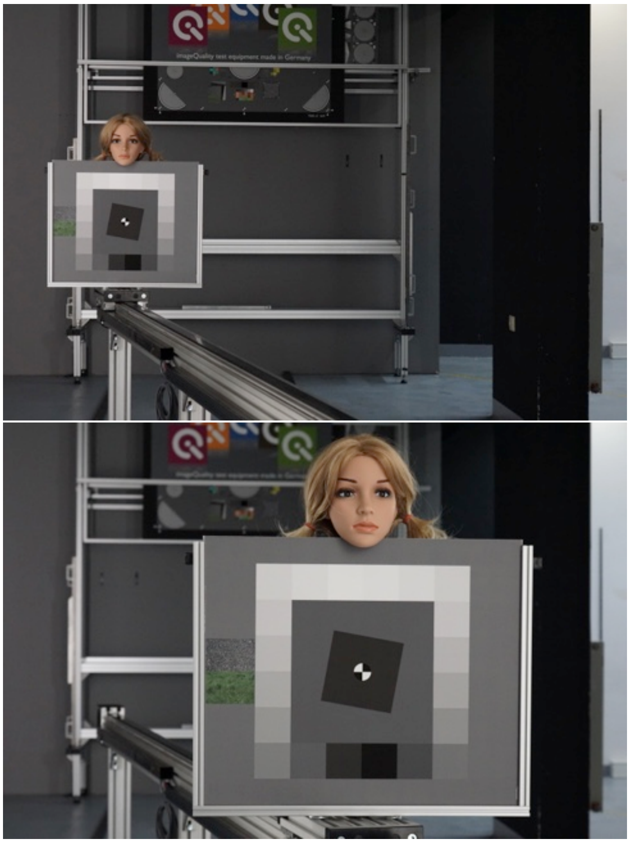


***Figure 10.*** *AF Tracking measurement setup. Example of captured images in minimum and maximum distance.*

For the published results, a selection of several cameras has been tested. This selection includes D-SLR and mirrorless system cameras, 8 cameras in total. We included two measurements with two different illumination level each into this paper.

For the first measurement, all devices have been set to single shot mode and the object speed was 0.4m/s. This reflects the use case of a walking person approaching the camera. Using a mechanical finger synchronized with the moving stage, as many images as possible where captured while the chart moves from the maximum distance to the minimum distance. The devices were set to focus priority, single-shot AF and automatic AF field selection.

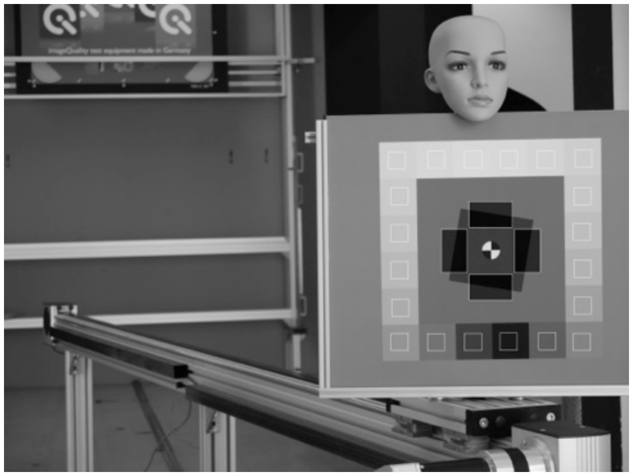


***Figure 11.*** *AF Tracking measurement image example. ROIs for analysis are drawn into the image (white rectangles). ROIs on grayscale used for linearization, ROIs on slanted edges used for analysis. Only edges within ROI are linearized in this image. As the chart is moving while capturing the images, only the top and bottom ROI have been included into the results to minimize the possible influence of motion blur.*

For the second measurement, all devices have been set to burst mode and the chart moves with 1m/s towards the camera. The target was to compare with at least (but not much more) 3 frames per second, so that all devices deliver at least 9 images per test sequence. Cameras that offer different speed level for their burst mode, the slower mode has been selected (if equal or faster 3fps). All setting have been made according to the manufacturer recommendations in the user manual for tracking moving objects.

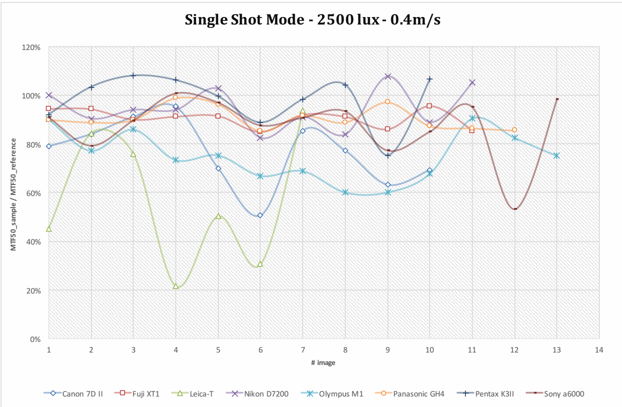
Both measurements have been performed under 300lux illumination and 2500lux illumination. All devices were equipped with standard zoom lenses and zoomed to an equivalent focal length of 70mm, set to f5.6. The ISO speed was set to ISO800 (at 2500lux) and ISO3200 (at 300lux) to have a no longer exposure time than 1/200s for any condition.

## Results

The numerical results and graphical plots for two measurements are shown in figures 12 & 13 (Single shot mode) and figures 14 & 15 (Burst Mode). The reported numerical results show the AF performance. The AF performance is defined as the ratio of the measured MTF50 value divided by the MTF50 value from a reference measurement. The reference measurement has been performed with the chart positioned in the center of the moving stage and therefore also in the image center. The reference has been measured for all 4 different conditions individually.

The measurement of the MTF50 value per image can vary with the position in the image field and differences in the system SFR depending on the object distance. So we have to allow a relatively large error per measurement which can also lead to AF performance value of $>100\%$.

We experienced significant differences in the performance of the AF tracking capabilities of the tested eight cameras. A general trend is that all devices perform better under the bright light con-




| Single Mode - 2500lx - 0.4m/s | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canon 7D II | Fuji XT1 | Leica-T | Nikon D7200 | Olympus M1 | Panasonic GH4 | Pentax K3II | Sony a6000 |
| 1 | 79% | 94% | 45% | 100% | 90% | 90% | 92% | 91% |
| 2 | 84% | 94% | 84% | 90% | 77% | 89% | 103% | 79% |
| 3 | 91% | 90% | 76% | 94% | 86% | 90% | 108% | 90% |
| 4 | 95% | 91% | 22% | 94% | 73% | 99% | 106% | 101% |
| 5 | 70% | 91% | 50% | 103% | 75% | 96% | 100% | 97% |
| 6 | 51% | 85% | 31% | 82% | 67% | 85% | 89% | 88% |
| 7 | 86% | 92% | 94% | 91% | 69% | 92% | 98% | 91% |
| 8 | 77% | 91% | | 84% | 60% | 89% | 104% | 93% |
| 9 | 63% | 86% | | 108% | 60% | 97% | 75% | 77% |
| 10 | 69% | 96% | | 89% | 68% | 87% | 107% | 85% |
| 11 | | 85% | | 105% | 90% | 86% | | 95% |
| 12 | | | | | 82% | 86% | | 53% |
| 13 | | | | | 75% | | | 98% |
| 14 | | | | | | | | |
| 15 | | | | | | | | |

***Figure 12.*** *AF Tracking Single Shot Mode - The camera captures images in single shot mode while the object is moving with 0.4m/s from far position (5m) to near position (2m). Graphical and numerical results for 2500lux illumination.*

dition and show lower AF performance under 300lux illumination level.

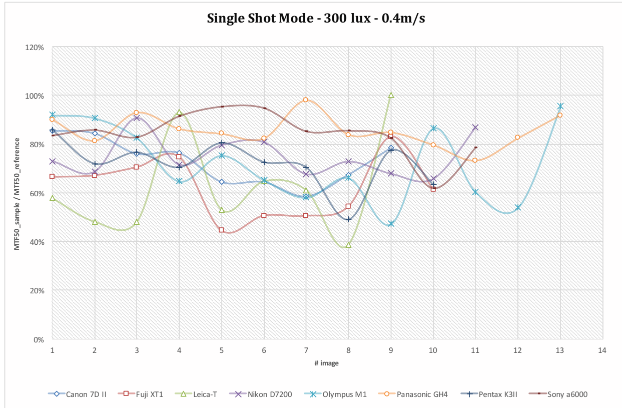
We see different behavior of devices that can be classified into these categories:

constant Devices and their AF system that fall into this category manage to keep the AF performance in a relatively small window, steady above 80%. That means that the devices can actually keep the object in focus when it is moving. An example for this is the Panasonic GH4 in all presented conditions.

on/off We observed devices that manage to keep the object in focus while moving, but fail after they performed well for some images. So the system lost track of the moving object, sometimes getting it back after some images. Example: Sony alpha6000 in both modes at 300lux.

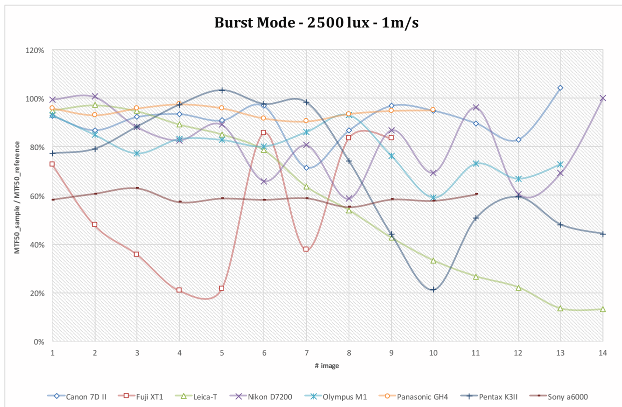
swinging While the devices manage to keep the focus somehow onto the object, they show increased fluctuation from frame to frame. This means that the focus is basically tracking the general movement of the object, but fails to put the focus exactly onto the object. Example: Nikon D7200 at all conditions, most obvious at burst mode with 1m/s movement.

no track Some devices failed to track the object at all. We see that the AF-Performance is good on the first image, but it constantly lowers with every following image. An example is the Leica T in burst mode. Under 300 lux, it managed to re-focus once, but otherwise did not follow the object at all.



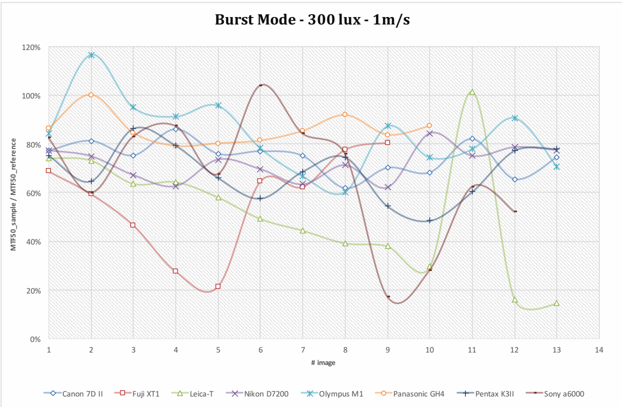

| Single Mode - 300lx - 0.4m/s | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canon 7D II | Fuji XT1 | Leica-T | Nikon D7200 | Olympus M1 | Panasonic GH4 | Pentax K3II | Sony a6000 |
| 1 | 86% | 66% | 58% | 73% | 92% | 90% | 86% | 83% |
| 2 | 84% | 67% | 48% | 69% | 91% | 81% | 72% | 86% |
| 3 | 76% | 70% | 48% | 91% | 83% | 93% | 77% | 83% |
| 4 | 76% | 75% | 93% | 72% | 65% | 86% | 70% | 91% |
| 5 | 65% | 44% | 53% | 80% | 75% | 84% | 80% | 95% |
| 6 | 64% | 51% | 65% | 81% | 65% | 82% | 73% | 95% |
| 7 | 59% | 50% | 61% | 68% | 58% | 98% | 70% | 85% |
| 8 | 67% | 54% | 39% | 73% | 66% | 84% | 49% | 85% |
| 9 | 78% | 83% | 100% | 68% | 47% | 85% | 77% | 82% |
| 10 | | 61% | | 66% | 87% | 80% | 63% | 62% |
| 11 | | | | 87% | 60% | 73% | | 78% |
| 12 | | | | | 54% | 83% | | |
| 13 | | | | | 96% | 92% | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |

***Figure 13.*** *AF Tracking Single Shot Mode - The camera captures images in single shot mode while the object is moving with 0.4m/s from far position (5m) to near position (2m).* ***top:*** *Graphical and numerical results for 2500lux illumination.* ***bottom:*** *Graphical and numerical results for 300lux illumination.*




| Burst Mode - 2500lx - 1m/s | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canon 7D II | Fuji XT1 | Leica-T | Nikon D7200 | Olympus M1 | Panasonic GH4 | Pentax K3II | Sony a6000 |
| 1 | 93% | 73% | 95% | 100% | 93% | 96% | 77% | 58% |
| 2 | 87% | 48% | 97% | 101% | 85% | 93% | 79% | 61% |
| 3 | 92% | 36% | 95% | 88% | 77% | 96% | 88% | 63% |
| 4 | 93% | 21% | 89% | 83% | 83% | 97% | 97% | 57% |
| 5 | 91% | 22% | 85% | 89% | 83% | 96% | 103% | 59% |
| 6 | 97% | 86% | 79% | 66% | 80% | 92% | 98% | 58% |
| 7 | 71% | 38% | 64% | 81% | 86% | 90% | 98% | 59% |
| 8 | 87% | 84% | 54% | 59% | 93% | 94% | 74% | 55% |
| 9 | 97% | 84% | 43% | 87% | 76% | 95% | 44% | 58% |
| 10 | 95% | | 33% | 69% | 59% | 95% | 21% | 58% |
| 11 | 90% | | 27% | 96% | 73% | | 51% | 60% |
| 12 | 83% | | 22% | 61% | 67% | | 59% | |
| 13 | 104% | | 13% | 69% | 73% | | 48% | |
| 14 | | | 13% | 100% | | | 44% | |
| 15 | | | | | | | | |

***Figure 14.*** *AF Tracking Burst Mode - The camera captures as many images as possible while the object is moving with 1m/s from far position (5m) to near position (2m). Graphical and numerical results for 2500lux illumination.*




| Burst Mode - 300lx - 1m/s | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canon 7D II | Fuji XT1 | Leica-T | Nikon D7200 | Olympus M1 | Panasonic GH4 | Pentax K3II | Sony a6000 |
| 1 | 77% | 69% | 74% | 77% | 84% | 86% | 75% | 82% |
| 2 | 81% | 60% | 73% | 75% | 117% | 100% | 65% | 60% |
| 3 | 75% | 47% | 64% | 67% | 95% | 85% | 86% | 83% |
| 4 | 86% | 28% | 64% | 63% | 91% | 79% | 79% | 87% |
| 5 | 76% | 21% | 58% | 74% | 96% | 80% | 66% | 68% |
| 6 | 77% | 65% | 49% | 70% | 78% | 81% | 58% | 104% |
| 7 | 75% | 62% | 44% | 63% | 67% | 85% | 69% | 84% |
| 8 | 62% | 78% | 39% | 71% | 60% | 92% | 75% | 76% |
| 9 | 70% | 81% | 38% | 62% | 87% | 84% | 54% | 17% |
| 10 | 68% | | 30% | 84% | 74% | 87% | 48% | 28% |
| 11 | 82% | | 101% | 75% | 78% | | 60% | 62% |
| 12 | 65% | | 16% | 79% | 91% | | 77% | 52% |
| 13 | 75% | | 14% | 77% | 71% | | 78% | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |

***Figure 15.*** *AF Tracking Burst Mode - The camera captures as many images as possible while the object is moving with 1m/s from far position (5m) to near position (2m). Graphical and numerical results for 300lux illumination.*

## Conclusion

- When testing the limiting resolution of a camera/lens combination, we have to assume that the AF system is not capable to achieve the best possible performance, even when selecting "best of 10". A MF sequence is required. We performed this test for the limiting resolution only, but it extremely likely that this result is also true for all other metrics that are direct or indirect related to the SFR of the system under test.
- Even though the main components of an AF system are part of the camera, the lens also has a significant influence. So when comparing cameras with each other, it is important to make wise decisions which lens is used for the evaluation. if possible, best solution is to use the same lens for different cameras.
- To track a moving object is still a difficult task for todays cameras and there is still a lot of room for improvement.
- We see that D-SLR cameras have a tendency to have a lower accuracy and repeatability in comparison to system cameras.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## References


[1] International Organization of Standardization, "ISO12233:2014 Photography - Electronic still picture imaging - Resolution measurements"

[2] Artmann, "Image quality assessment using the dead leaves target: experience with the latest approach and further investigations", Electronic Imaging Conference, Proc. SPIE 9404, Digital Photography XI, 94040J (27 February 2015); doi: 10.1117/12.2079609

[3] Artmann, "Linearization and Normalization in Spatial Frequency Response Measurement", IS&T International Symposium on Electronic Imaging, Image Quality and System Performance XIII, IQSP-011.1

[4] International Organization of Standardization, "ISO15781:2013 Photography – Digital still cameras – Measuring shooting time lag, shutter release time lag, shooting rate, and start-up time"

[5] Artmann, Wueller,"Interaction of image noise, spatial resolution, and low contrast fine detail preservation in digital image processing", Electronic Imaging Conference, Proc. SPIE, Vol. 7250, 72500I (2009)

[6] Loebich,Wueller,Klingen,Jaeger, "Digital Camera Resolution Measurement Using Sinusoidal Siemens Stars", Electronic Imaging Conference, SPIE Vol. 6502, 65020N (2007)


## Author Biography

*Uwe Artmann studied Photo Technology at the University of Applied Sciences in Cologne following an apprenticeship as a photographer, and finished with the German 'Diploma Engineer'. He is now CTO at Image Engineering, an independent test lab for imaging devices and manufacturer of all kinds of test equipment for these devices. His special interest is the influence of noise reduction on image quality and MTF measurement in general.*