Improving texture loss measurement: spatial frequency response based on a colored target

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ABSTRACT

The pixel race in the digital camera industry and for mobile phone imaging modules have made noise reduction a significant part in the signal processing. Depending on the used algorithms and the underlying amount of noise that has to be removed, noise reduction leads to a loss of low contrast fine details, also known as texture loss. The description of these effects became an important part of the objective image quality evaluation in the last years, as the established methods for noise and resolution measurement fail to do so. Different methods have been developed and presented, but could not fully satisfy the requested stability and correlation with subjective tests. In our paper, we present our experience with the current approaches for texture loss measurement. We have found a critical issue within these methods: the used targets are neutral in color. We could show that the test-lab results do not match the real live experience with the cameras under test. We present an approach using a colored target and our experience with this method.

Keywords: image quality evaluation, texture, noise reduction, spatial frequency response, kurtosis, SFR, Dead Leaves, MTF

1. INTRODUCTION

To get a full impression of the image quality of a digital camera, the test needs to include a measurement of the so called texture loss next to methods for noise and resolution measurement. At present, there are no standardized methods to measure the influence, even though this is an important topic and several people are working on this. Important requirements for test methods that can be used for image quality analysis are:

- It should not need a Full-Reference, so it can be obtained by taking an image of a known test target. By knowing the target and analyzing the image of the target, one can obtain information about the system.
- It shall not include any kind of subjective evaluation. Human observers are not objective enough to get comparable results over a long period of time and/or huge amount of cameras. Standardized testing with human observers can minimize this problem, but are extremely time consuming and therefore expensive.
- Even though it does not include subjective testing, the objective results shall have a good correlation with the image quality experienced by human observers. That way the method can substitute subjective testing and makes tests much faster.
- Ideally, the output is simple to understand and has just a single numerical value. This makes comparison between different cameras much easier and inexperienced people can understand ("The lower this number, the better the result.")

For more than three years, Image Engineering is using a method that is based on the measured kurtosis in the image a camera took of a gaussian white noise patch.[1,2,7] The idea is, that the statistical value "kurtosis" is 0 for a normal distribution of digital values found in white gaussian noise. All kind of linear filtering (like lens MTF or blur filter) will change the image content, but does not change the kurtosis. Only non-linear filtering as

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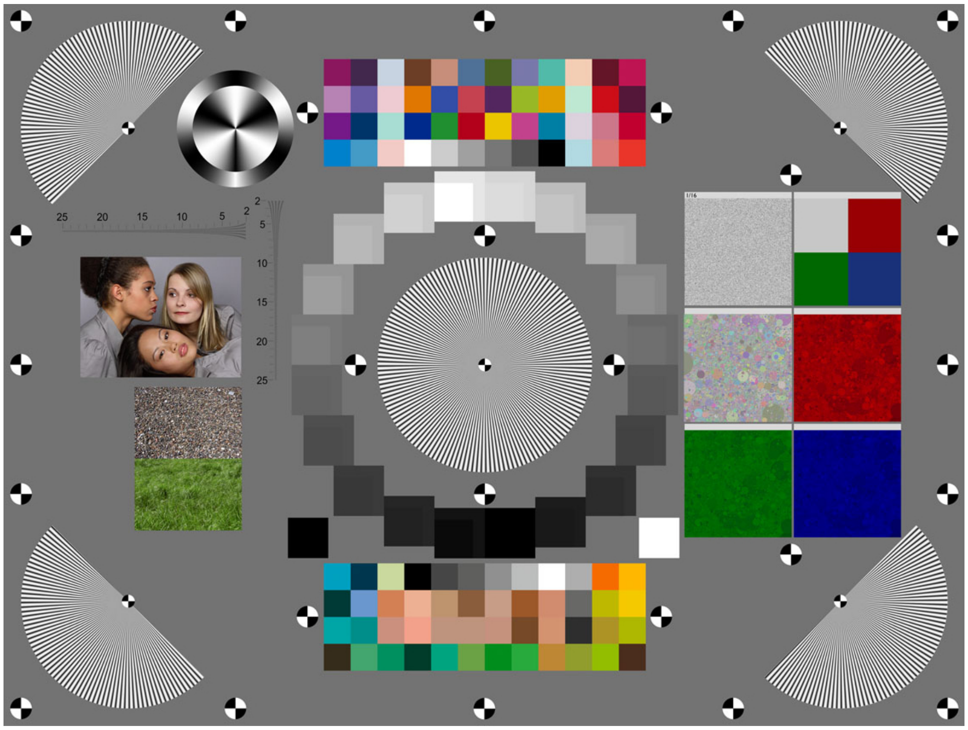

Figure 1. The used chart for camera image quality evaluation. It combines several structures for image quality evaluation including the influence of noise reduction.

found in noise reduction will change the distribution and therefore result in a higher value of the kurtosis. We had good experience with this method, but it failed in one important requirement: It is not easy to understand and it always needs some interpretation. The kurtosis value always needs to be seen in context of noise and resolution and is more a good indicator than a stable measurement.

Different methods have been discussed among the experts and one proposal[6] was based on a target called "Dead Leaves", as it is somewhat similar to a huge pile of dead leaves of trees, found in fall (see: Fig. 3). The first presented implementations could not fulfill the expectations, but with some modifications presented by McElvain et al.,[5] it seemed promising that a good method was found.

End of 2010, Image Engineering had the demand to develop a test target that can provide the most important aspects of image quality. We decided to include gaussian white noise into the target (Fig. 1) to be able to measure the kurtosis and to include the dead leaves structure (Fig. 3) with the reference patch as proposed by McElvain et al.[5] Next to other structures to obtain the OECF and to measure noise, color reproduction and other aspects, we included some natural objects to have a reference (Fig. 2). As the results from this target are used for magazines, the authors need some structures they can use to explain the results to their reader.

To evaluate the new chart and the new methods, several different cameras have been tested. This included cameras with known low performance in texture loss and some D-SLR cameras. The images and the results have been reviewed by trained personnel of Image Engineering and editors of the german photography magazine Colorfoto. With this feedback, we have found issues with the methods and also have found solutions to overcome these issues.

2. CHART

The used dead leaves structure was created following a model, that opaque circles are stacked and the radii of these circles follow a $1/r^3$ probability distribution. The radii are limited to a minimum and maximum, so no circle can be smaller than print resolution and too large to fully cover the image. The gray value of the circles

Figure 2. Natural objects in the charts to compare subjective and objective evaluation. *top left:* gravel *bottom left:* lawn *right:* portraits (Part of Fig.1)

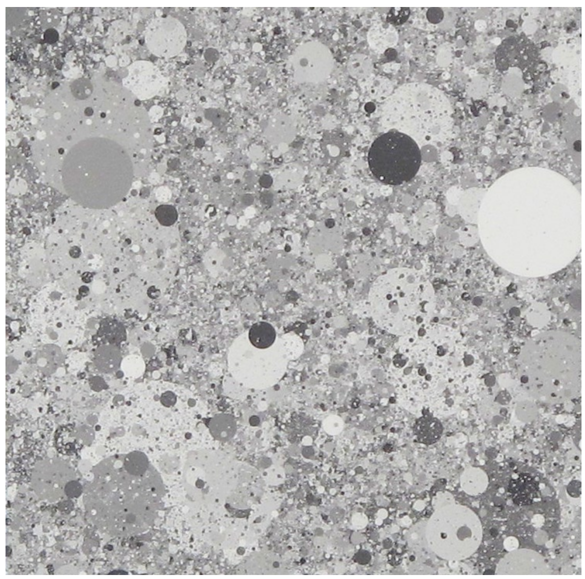

Figure 3. The dead leaves structure in the first version of the chart (circles with a probability function of radius and gray value). (Part of Fig.1)

is chosen with a uniform distribution in a range of 25% and 75% of maximum density produced by the print process.

After the first round of taking images of the chart, we have found differences in the evaluation between the engineers at Image Engineering and the staff at Colorfoto. We found that both parties came to a different ranking of the images if checking for texture loss. The editors have have found their experience with the cameras under test in the images. So their experience based on the usage of the cameras in daily life was also found in the images we have taken from the multi purpose chart. By just visually evaluating the images, Image Engineering's staff came to another ranking and has seen different behavior of the camera. After a short discussion, we found the main reason for this observation: The less technical group of Colorfoto (with the good correlation to their subjective experience) had checked the behavior based on the natural objects on the chart (Fig. 2), the engineers have checked based on the dead leaves structure (Fig. 3). So we have seen:

- The behavior of the cameras under test was different if reproducing lawn, gravel and portraits compared to the dead leaves structure.
- The behavior of the cameras under test reproducing the natural objects in the chart matched the experience the editors made with the cameras in "real live tests".

Combining these findings, we come to the conclusion:

- The dead leaves structure (gray version) is not adequate as test target for texture loss measurements as it does not reflect the seen behavior in natural objects.

So we knew that we have to change the chart and not (only) the algorithm be used to analyze the image. The main difference between the natural objects and the dead leaves structure is, that the dead leaves structure is gray only. Nearly all cameras for photography purpose on the market work with a bayer pattern and need to interpolate the missing color information per pixel. This demosaicing also has an influence on the SFR (spatial frequency response) of the camera. Noise reduction algorithms can treat intensity and color information differently, so a pure gray chart does not reflect the behavior of the camera on colored targets.

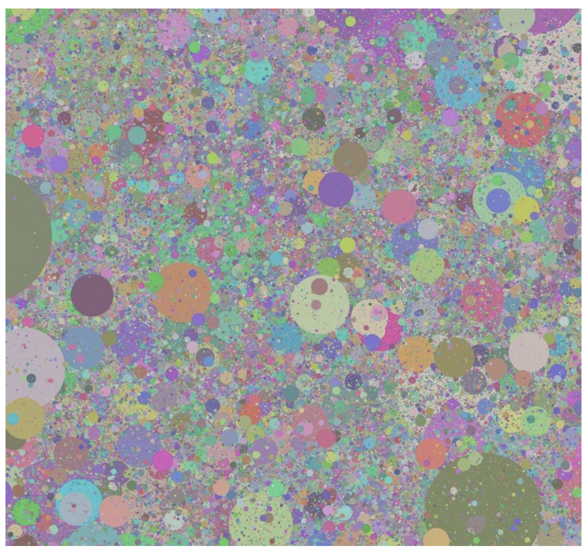

Figure 4. The colored dead leaves target

Taking this into account, it is clear that the test chart has to be colored. As we had also seen, that the measurement results based on the gray dead leaves target reflected what we have seen in the image of this structure, we decided that the algorithm itself seems to work, but the target needs modifications. So we produced a colored dead leaves target (Fig. 4). We extended the model of the chart from a uniform distribution of gray values to a uniform distribution of R, G, B, so the red, green and blue color channel independently. This results in a colorful target and the statistics in the intensity channel (a weighted sum of R, G, B) is kept as in the gray chart. Also the mean value of R, G and B results in a gray patch which can be used for the needed reference measurement. So the basic algorithm (see Sec. 3) can be applied to the image data for both type of charts (gray and colored dead leaves).

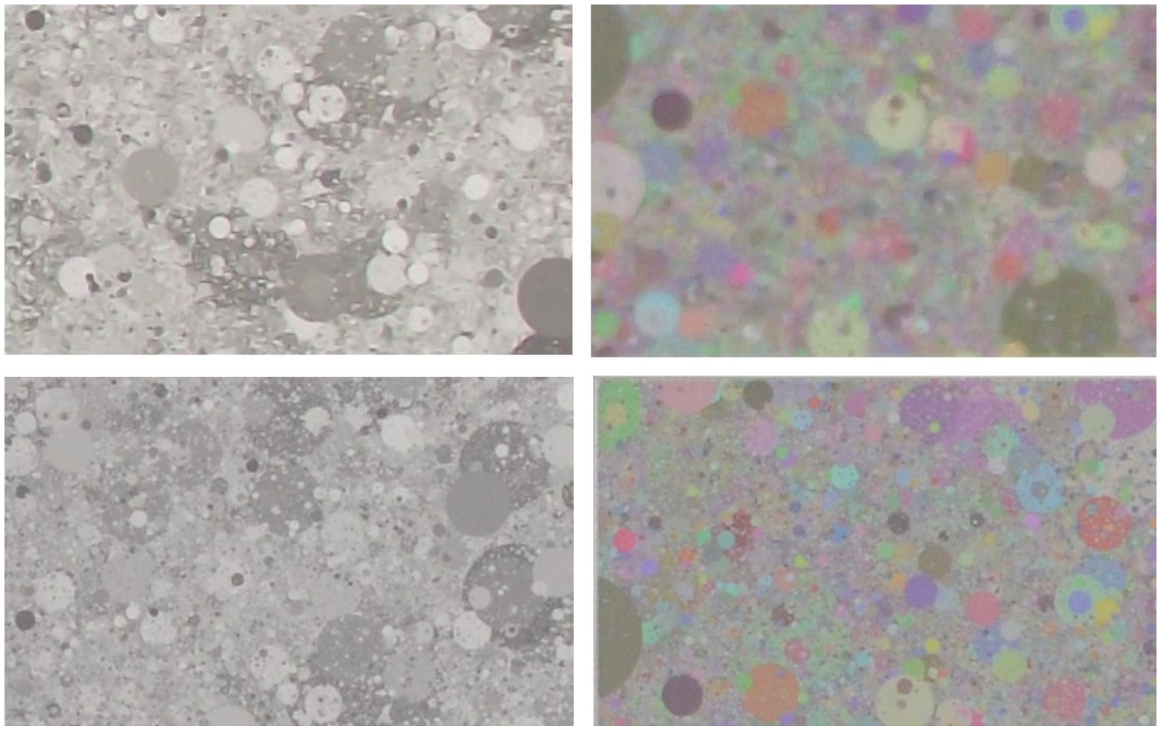

Figure 5. Sample of different camera behavior; *top:* Fujifilm S2800HD *bottom:* Nikon D7000; *left:* Gray Dead Leaves *right:* Colored Dead Leaves

3. OBTAINING THE SFR

The basic concept to obtain the Spatial Frequency Response (SFR) is to measure the power spectrum (PS) found in the image. The image is a reproduction the camera under test has made from the dead leaves target. The PS of the target is known, so by simply dividing these two PS, one gets the SFR. As could be shown[3] that this algorithm is influenced by camera noise, it was extended[5] by a reference measurement on a gray patch that has the same intensity as the mean value of the dead leaves structure.

$$SFR(f) = \sqrt{\frac{PS_{image}(f) - PS_{noise}(f)}{PS_{target}(f)}} \tag{1}$$

The calculation is done in this steps, assuming the camera under test has reproduced the dead leaves target and a reference patch which is the mean value of the dead leaves structure and is homogenous. Additional gray patches with a known reflectance are available to obtain an opto electronic conversion function (OECF) for linearization as cameras do not deliver linear OECF.

- Calculate $PS_{target}(f)$ (PS of dead leaves target) using the meta information from chart production process.
- Read ROI of dead leaves patch, reference patch and gray patches.
- Calculate OECF with image data from gray patches and the known reflectance of these patches. The OECF here is a function of reflectance vs. Y (Y is a weighted sum of R, G, B)
- Calculate Y image from the RGB image of dead leaves patch and reference patch.
- Linearize using the inverse of the OECF.
- Calculate $PS_{image}(f)$ (from dead leaves patch) and $PS_{noise}(f)$ (from the reference patch).

- Calculate SFR(f) using Equation 1.

The calculation of the PS includes a reduction process from the 2D spectrum to 1D data and the calculation of the SFR includes a normalization process for presentation purposes. This algorithm is applied to the gray dead leaves target as well as to the colored dead leaves target.

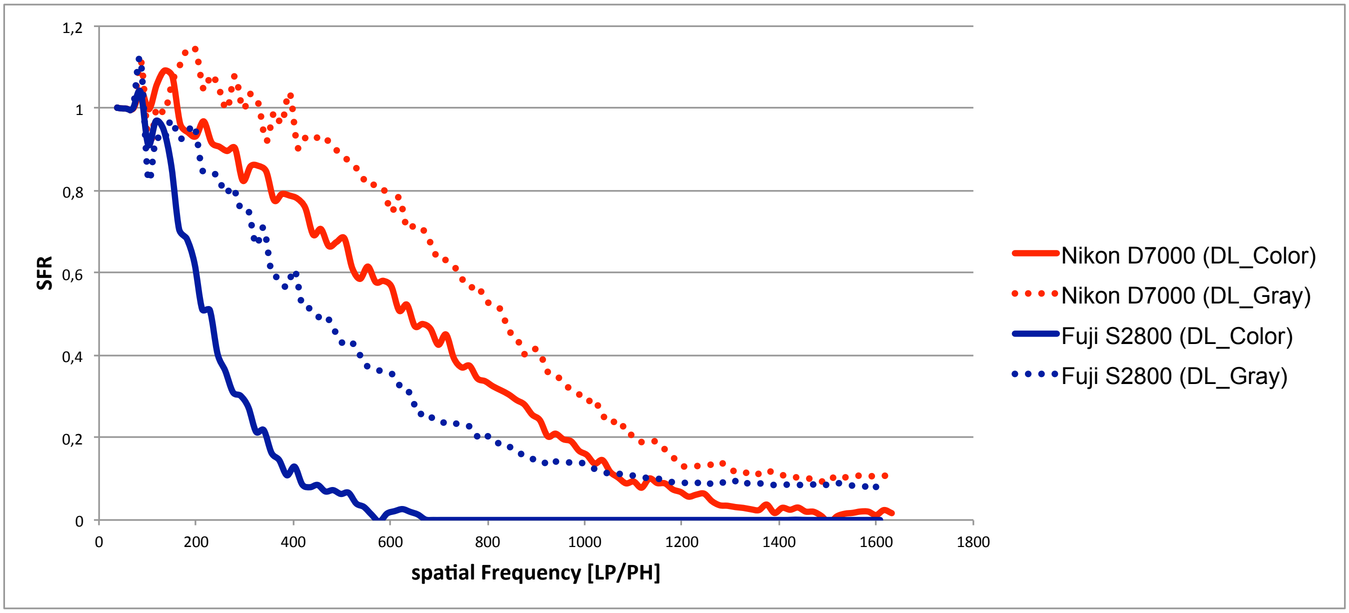

Figure 6. Comparison of SFR; Nikon D-7000 (D-SLR, ISO800) and Fujifilm S2800HD (Compact, ISO100); Colored Dead Leaves and Gray Dead Leaves; the colored Dead Leaves leads to a significant lower SFR; effect stronger for compact than for D-SLR

4. FROM SFR TO A SINGLE VALUE

A plotted SFR contains a lot of information that a trained person can interpret. But in a lot of cases, the complete SFR is too much information, as it makes it hard to compare different cameras and to make a simple statement which result is better than the other. So for purpose of ranking and comparison, the SFR needs to be reduced to a single value. This is a difficult task, as it needs an algorithm that throws away a huge amount of data while preserving the essential information. Based on the SFR obtained from a variety of cameras, we tried three different methods to simplify a SFR to one number and applied these to the data.

"MTF10" Based on the Rayleigh Criterion, the limiting resolution of a camera system is reported as the highest spatial frequency that results in a modulation or spatial frequency response of $\leq$ 10%. This value is suitable for checking the optical performance of a camera system and can be interpreted as the limiting resolution. The higher the value, the better the limiting resolution.

"MTF50" The "MTF50" value is the highest spatial frequency that results in a modulation or spatial frequency response of $\leq$ 50%. If checking for lens performance, this value is more related to the performance in the mid frequencies the lens-camera system delivers. The higher the value, the better.

"Acutance" This value needs a more complex calculation. The idea is to take the Contrast Sensitivity Function (CSF) of the human visual system into account, so to weight the performance of a system against the importance of the spatial frequencies for the perception. The implementation we have chosen was discussed among imaging experts at working groups of ISO and I3A. The obtained SFR is filtered with the CSF and the integral of the resulting function is divided by the integral of an ideal MTF filtered with the CSF in the same spatial frequency range. The higher, the better the performance of the camera under test. As the CSF needs to be calculated for a specific viewing condition, we have chosen to calculate this value for two different scenarios: (A) 100% view on a 96ppi display in 0.5m distance eye-display and (B) a 40cm height print (not limited by print technology) and a viewing distance which is equal to the diagonal of the print.

5. RESULTS

Camera			**Nikon D7000**	**Pentax K-5**	**FujiFilm S2800**
Type			D-SLR	D-SLR	Compact
Pixelcount			16.2 MP	16.3 MP	13.8 MP
Gray DL	MTF10	ISO100	-	-	-
		ISO400	-	-	817
		ISO800	1463	-	X
		ISO1600	1283	-	1056
	MTF50	ISO100	947	957	640
		ISO400	923	935	332
		ISO800	831	895	X
		ISO1600	739	956	245
	Acutance_Set A	ISO100	0,51	0,88	0,37
		ISO400	0,49	0,86	0,38
		ISO800	0,44	0,84	X
		ISO1600	0,44	0,84	0,96
	Acutance_Set B	ISO100	1,05	1,11	0,85
		ISO400	1,02	1,09	0,62
		ISO800	0,97	1,09	X
		ISO1600	0,93	1,07	0,51
Colored DL	MTF10	ISO100	1180	1564	398
		ISO400	1007	1327	295
		ISO800	822	1592	212
		ISO1600	965	-	213
	MTF50	ISO100	534	1026	230
		ISO400	458	858	182
		ISO800	446	929	158
		ISO1600	496	930	140
	Acutance_Set A	ISO100	0,50	0,90	0,19
		ISO400	0,53	0,77	0,05
		ISO800	0,41	0,80	-
		ISO1600	0,45	0,78	-
	Acutance_Set B	ISO100	0,82	1,11	0,46
		ISO400	0,77	1,03	0,32
		ISO800	0,76	1,04	0,20
		ISO1600	0,80	1,01	0,07

Figure 7. Table of measurement results; (-) Calculation not possible (X) Data not available

As can be seen in Figure 6, the SFR is lower if using a colored dead leaves target. This reflects the behavior as seen in all cameras and shown as sample in Figure 5.

The difference between the Nikon D7000 and the Pentax K-5 is visible in natural images, but it could not be shown on the gray dead leaves target. In Figure 8 one can see, that on the colored dead leaves target, this difference in texture loss can be seen. As shown in Figure 7, the numeric results also show this. While on the gray dead leaves target the results are not significantly different, they are on the colored dead leaves target. So the advantage of the colored dead leaves target is obvious.

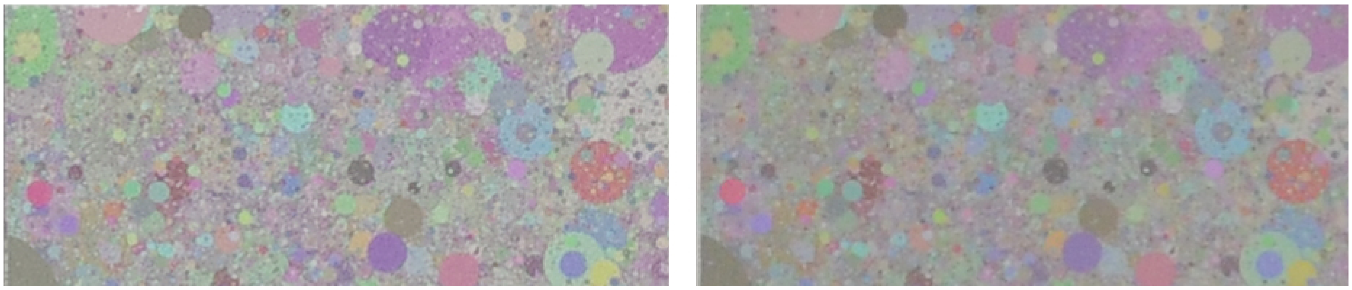

Figure 8. Image Sample: Detail of Colored Dead Leaves structure; Pentax K-5 (left) vs. Nikon D7000 (right); both ISO800;

The MTF10 value is not a good way to show the differences in the texture loss performance, as the SFR in a lot of cases does not have values below 10%, so a calculation is not possible.

The performance of compact cameras and mobile phones can be very poor and the numerical results very low. The filtering with the CSF for 100% view on a display, where we have a higher weight on high spatial frequencies, is misleading and results in too low values that do not represent the actual behavior.

Compared to the few subjective judgements we had from editors and our own evaluation, the acutance approach results in a different ranking of the numerical results. This should be topic of future work to evaluate this in more detail.

6. CONCLUSION AND FUTURE WORK

We could show that the type of target has an important influence on the measurement results. The usage of gray targets is not suitable for the measurement of the so called "texture loss", which means the loss of low contrast, fine details. In our experience, the colored version of the dead leaves target is a good test chart, as cameras treat it in a very similar way as real, natural objects are treated.

The algorithm to obtain the SFR can be applied on both version of the dead leaves target (gray and colored). The resulting SFR is a good representation of the observed behavior of the camera under test.

The reduction of the complex data of an SFR to a single number is a difficult task and we have seen, that neither the MTF50 nor the acutance approach could show significant advantages in the data set we have used for this work. We have decided to use the MTF50 value as single value for ranking and comparison, as we could see these advantages over the acutance approach:

- The MTF50 value gives higher differences between different cameras, so a ranking and comparison is easier.
- The MTF50 value is easier to understand and to communicate to non-technical readers.
- Different shapes of SFR can result in similar values for the acutance approach. Even if this has not been finalized yet, we have the feeling that the MTF50 value correlates better with subjective image quality rating.

The reduction to a single value is subject to ongoing work on this topic.

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