Image quality assessment using the dead leaves target: experience with the latest approach and further investigations

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ABSTRACT

The so-called texture loss is a critical parameter in the objective image quality assessment of todays cameras. Especially cameras build in mobile phones show significant loss of low contrast, fine details which are hard to describe using standard resolution measurement procedures. The combination of very small form factor and high pixel count leads to a high demand of noise reduction in the signal-processing pipeline of these cameras. Different work groups within ISO and IEEE are investigating methods to describe the texture loss with an objective method. The so-called dead leaves pattern has been used for quite a while in this context. Image Engineering presented a new intrinsic approach at the Electronic Imaging Conference 2014, which promises to solve the open issue of the original approach, which could be influenced by noise and artifacts. In this paper, we present our experience with the new approach for a large set of different imaging devices. We show, that some sharpening algorithm found in todays cameras can significantly influence the Spatial Frequency Response based on the Dead Leaves structure ($SFR_{DeadLeaves}$) results and therefore make an objective evaluation of the perceived image quality even harder. For an objective comparison of cameras, the resulting SFR needs to be reduced to a small set of numbers, ideally a single number. The observed sharpening algorithms lead to much better numerical results, while the image quality already degrades due to strong sharpening. So the measured, high $SFR_{DeadLeaves}$ result is not wrong, as it reflects the artificially enhanced SFR, but the numerical result cannot be used as the only number to describe the image quality. We propose to combine the $SFR_{DeadLeaves}$ measurement with other SFR measurement procedures as described in ISO12233:2014. Based on the three different SFR functions using the dead leaves pattern, sinusoidal Siemens Stars and slanted edges, it is possible to obtain a much better description if the perceived image quality. We propose a combination of $SFR_{DeadLeaves}$, SFR_{Edge} and $SFR_{Siemens}$ measurements for an in-depth test of cameras and present our experience based on todays cameras.

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

1. INTRODUCTION

In 2014 we introduced a new approach to evaluate digital camera for their reproduction of low contrast, fine details. The so called texture loss is evaluated using the already known pattern "Dead Leaves" (see Fig. 7). The main difference to previously existing analyzing methods is the intrinsic approach. Instead of just using the power spectrum of the target, which can be well estimated from the probability distribution used for the creation of the pattern,[8] it uses the known spatial information of the pattern. So in terms of test methods, we are performing a full-reference method instead of a semi-reference method (see Sec.2). This has the big benefit, that we can check for the complete transfer function instead of only for the amplitude response. The important phase information is maintained and considered, which makes the method more robust against added image content like noise or artifacts.

While we only had first impressions of the performance of the new algorithm[1] when presenting it at the Electronic Imaging Conference in 2014, we could already see that is is very promising. For a not very small group of devices, the old approach of analyzing the dead leaves pattern lead to apparently wrong results, while the new approach could provide a good description of the experienced texture loss (Fig.1). We gained more

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experience over the last year and in this paper we present our experience with the new approach. For the purpose of a complete description of the behavior of a digital camera system, we apply different resolution test methods at the same time.

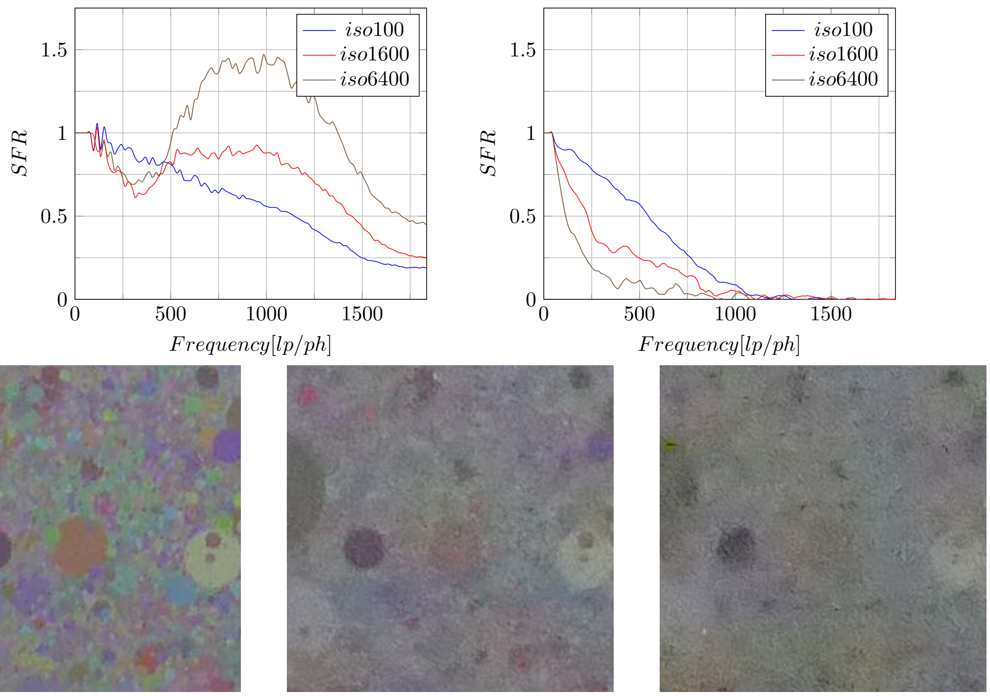

Figure 1: Comparison of Dead Leaves methods - Panasonic Lumix DMC-TZ41
top left: $SFR_{DL_{direct}}$ - the first approach, does not reflect visual impression
top right:$SFR_{DL_{cross}}$ - the new approach, the visual impression is reflected in the SFR
bottom from left to right: Image Details: ISO100, ISO1600, ISO6400

2. METHODS

For the assessment of digital cameras regarding spatial resolution, sharpness and texture blur, we combine different methods. For a quick assessment and convenient workflow, we combine the needed test pattern into a single, multi-purpose test target (see Fig.2). All used methods have in common, that they provide the SFR (spatial frequency response) based on the used test pattern. So after the analysis of the image, these different SFR functions are available:

- $SFR_{Siemens}$
- SFR_{Edge}
- $SFR_{DeadLeaves}$

The most interesting is to compare the SFR itself with each other, but ranking and quick access to the data, we need to reduce the SFR to single numerical values. For this purpose, we use these values:

- *MTF10* - the spatial frequency that leads to a SFR of 10%. This value is also referred to as *limiting resolution*, as it describes the maximum reproducible spatial frequency of the device under test. The 10% limit is derived from the Raleigh Criterion, which states that the minimum resolvable detail is reached when the first diffraction minimum of the image of one source point coincides with the maximum of another.

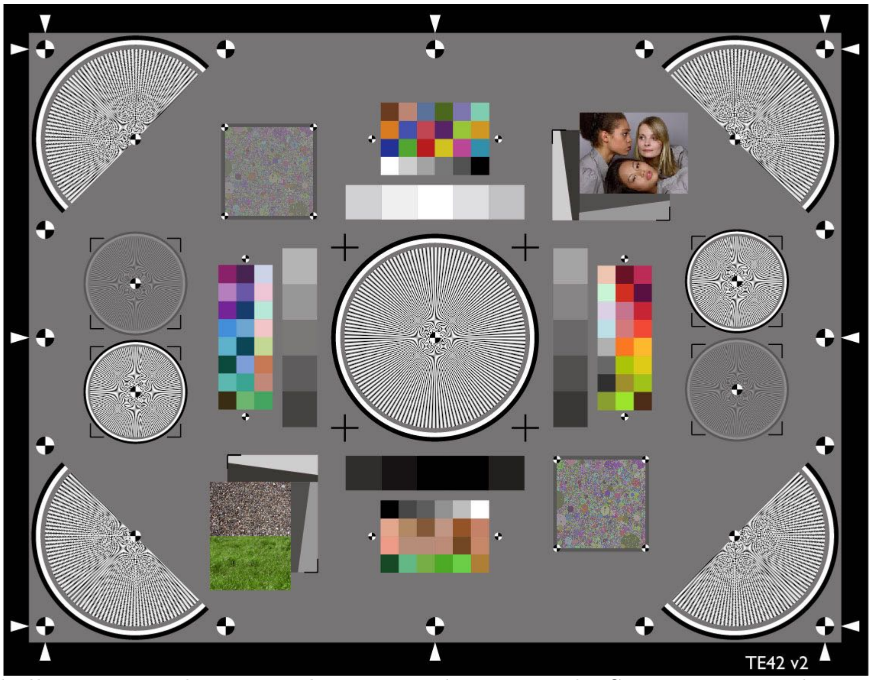

Figure 2: The used all-in-one testchart. For this paper relevant are the Siemens star in the center ($SFR_{Siemens}$), the medium contrast and low contrast dead leaves pattern (SFR_{DL}) and the slanted edges (SFR_{Edge})in two different contrast ratios. The calculation of $SFR_{DL_{direct}}$ and $SFR_{DL_{cross}}$ is based on the same structures, using the gray background as noise reference for the $SFR_{DL_{direct}}$ analysis.

- *MTF50* - the spatial frequency that leads to a SFR of 50%. While the *MTF10* value describes the minimum resolvable detail, it does not reflect the SFR in lower spatial frequencies, which contribute to the subjective measure of *sharpness*. The *MTF50* value reflects the perceived *sharpness* much better.

- *Acutance* - a metric calculated with respect to the viewing condition of the observer. The acutance shall correlate with the subjective measure *sharpness*. It is the ratio of two integrals, both take the integral over all spatial frequencies from 0 to the Nyquist frequency f_{nyq} which is the theoretical maximum spatial frequency of the device under test. Enumerator is the integral of the SFR multiplied with the Contrast Sensitivity Function (CSF)*. The CSF can be adjusted to different assumptions of viewing conditions. Denumerator is the integral of the SFR multiplied with the theoretical ideal SFR. As this theoretical ideal SFR equals 1 for all spatial frequencies within the integral, it is not shown in Equation 1.

$$Acutance = \frac{\int_0^{f_{nyq}} SFR(f) \times CSF(f)\, \mathrm{d}f}{\int_0^{f_{nyq}} SFR(f)\, \mathrm{d}f} \tag{1}$$

2.1 $SFR_{Siemens}$

This method is part of the ISO12233:2014[7] standard for resolution measurement. It uses a siemens star with a harmonic function depending on the angle φ, taking the center of the star as the base of the angle. It provides a Modulation Transfer Function *MTF* which describes the loss of modulation depending on the spatial frequency. As the method is part of an international standard and has been explained in detail in previous papers[6,4,9] it will not be explained in detail in this paper.

*The CSF is a model of the perception of spatial frequencies by the human visual system. In our case, we use the CSF as described in the S-CIELab metric.

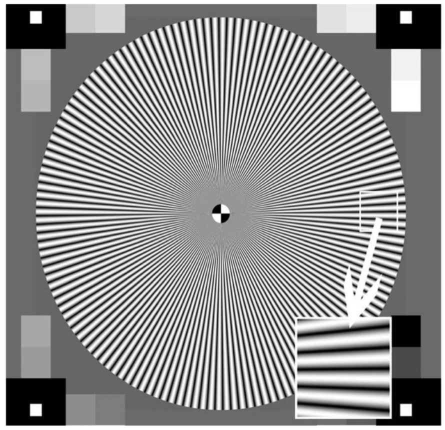

Figure 3: The sinusoidal Siemens start as described in ISO12233:2014

If not otherwise stated, the $SFR_{Siemens}$ or the derived numbers from the $SFR_{Siemens}$ are based on the average over all segments of the used star, so it includes the resolution in horizontal, vertical and diagonal orientation.

2.2 SFR_{Edge}

The SFR_{Edge} algorithm is described in ISO12233 and is based on the reproduction of a slanted edge in the image field. The over-sampled description of the edge is called the edge spread function *ESF*. The first derivative of the ESF is the line spread function *LSF*[†]. The SFR_{Edge} is the Fourier transform of the LSF. Before the transformation, the data is windowed to avoid leakage (see Fig.5).

Figure 4: Details of the used test chart. Compare upper right and lower left area of the entire chart shown in figure 2. The shown ladies and the grass/gravel area are for visual assessment only, the analysis is based on the slanted edges surrounding them. *top and left:*: 60%edge *right and bottom:*: 80%edge

For this paper, we analyzed four edges in the image. Two different contrasts are used and each of them is available in horizontal and vertical orientation. If not otherwise stated, the reported SFR_{Edge} is the average of the horizontal and vertical edge. The different contrast of the edges are a low contrast edge (60% edge modulation contrast as defined in ISO12233:2014 Annex C) and a high contrast edge (80% edge modulation contrast). Different contrasts are used as the sharpening algorithms in the image signal processor of todays cameras may detect the edge contrast and adjust the sharpening according to this.

[†] The LSF can be imagined as a 1-D representative of the point-spread function PSF

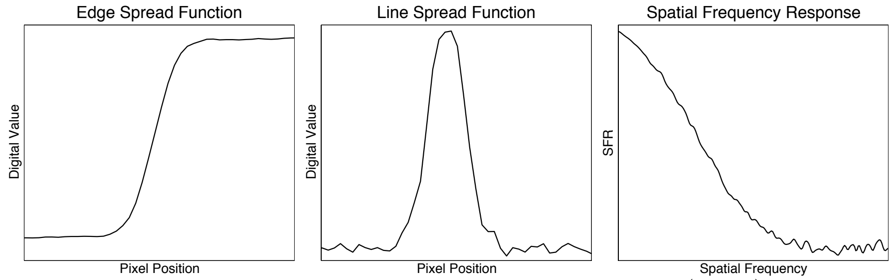

Figure 5: Basic concept of the SFR_{Edge} approach: The edge spread function (ESF) is the over sampled intensity function of the edge. The first derivative of this function equals the line spread function (LSF). The Fourier analysis gives the SFR.

2.2.1 Sharpening

In the analysis process of the slanted edge, the ESF can also be extracted and used for further analysis. Digital sharpening mostly appears in the image as undershoot and overshoot along edges. The ESF can be used to describe the undershoot and overshoot. If not otherwise stated, the metric **sharpening** equals the sum of overshoot and undershoot measured as the size of the area below or above the ESF created by the sharpening (see marked area in Figure 6).

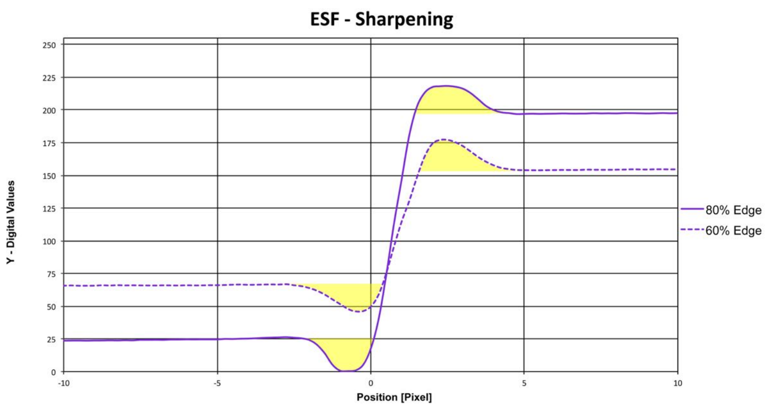

Figure 6: Example ESF of a Canon EOS 6D, JPEG, 60%edge and 80%edge. The sharpening is measured as the additional area created by underhoot or overshoot (see marked area in this graph).

2.3 $SFR_{DeadLeaves}$

The dead leaves pattern (see Fig.7)is created by placing circles at a random position with a random size and a random gray value. If the probability function is known, the power density spectrum of the target can be well estimated. For the very first approach,[2] this was already the key point to perform the analysis. The spatial content of the target $X(f)$ is transferred by the camera into the spatial image content $Y(f)$. The transfer function of the camera $H(f)$ is the wished information, as it represents the SFR of the camera system. In this assumption, the image content $Y(f)$ equals the product of $X(f)$ and $H(f)$ (see Eq.2) . Based on this assumption, the easiest approach is to divide the power spectrum of the image $\phi_{YY}(f)$ by the power spectrum of the target $\phi_{XX}(f)$ (see Eq.3). This provides the amplitude response of the system which can be seen as the SFR of the camera.

$$Y(f) = X(f)H(f) \tag{2}$$

$$|H(f)| = \sqrt{\frac{|\phi_{YY}(f)|^2}{|\phi_{XX}(f)|^2}} \tag{3}$$

This approach was the first presented version and it could be shown[34] that it is missing an important aspect. The used model misses that a camera does not only transfer spatial frequencies, but it also adds spatial information (noise, artifacts, etc.). A further development of the method was presented by McElvain et.al.[3] in 2010. This method is what we call $SFR_{DeadLeaves_{direct}}$ in this paper, as it directly uses the power spectrum of the target, the image and a reference patch. The new approach we presented 2014[1] is called $SFR_{DeadLeaves_{cross}}$ as it is based on the cross power density distribution.

The dead leaves pattern is available in two different contrast ratios. These are named *medium* and *low* in the results section of this paper.

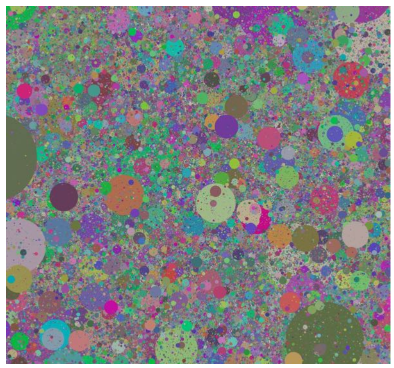

Figure 7: The colored dead leaves target

2.3.1 direct

The $SFR_{DeadLeaves_{direct}}$ method is an extension to the first presented approach. It takes into account that the camera does also add noise to the image content, therefore the results are influenced by the noise. Next to the dead leaves pattern, a gray reference patch is captured in the same image. The noise power spectrum $\phi_{NN}(f)$ measured on this reference patch is used as a correcting factor (see Eq. 4).

$$|H(f)| = \sqrt{\frac{|\phi_{XX}(f)|^2 - |\phi_{NN}(f)|^2}{|\phi_{YY}(f)|^2}} \tag{4}$$

This methods was only slightly modified by switching from a gray target to a colored version of the dead leaves pattern[5] and has been used for years in our lab. Unfortunately we identified more and more cameras that would get good measurement results based on this method but visually showed a significant loss of low contrast, fine details. This problem can be explained by the assumed signal model itself. While we at first assume that the camera is using non-linear operations like noise reduction (the reason we apply this analysis), for the analysis it is assumed that the added noise to a structure can be measured by analyzing a uniform reference patch. So it is assumed that the noise is identical on a uniform patch compared to a structured region of the image. This assumption does not hold true for cameras that apply noise reduction.

2.3.2 cross

While all other methods follow the concept of a semi-reference method[‡], the $SFR_{DeadLeaves_{cross}}$ follows the concept of a full reference method[§].

The flow chart in Figure 8 illustrates the algorithm. The SFR is calculated as well from the obtained transfer function $H(f)$. The biggest difference to the previous approach is that in this case we can calculate with the complex transfer function, as we still have the phase information. The *direct* approach uses the amplitude response only, therefore it can not distinguish between spatial information that has already been in the target and spatial information that has been added by the camera system. So noise that is different from the noise shown in the reference patch and any kind of artifacts added to the image have an influence on the measurement results in the *direct* approach.

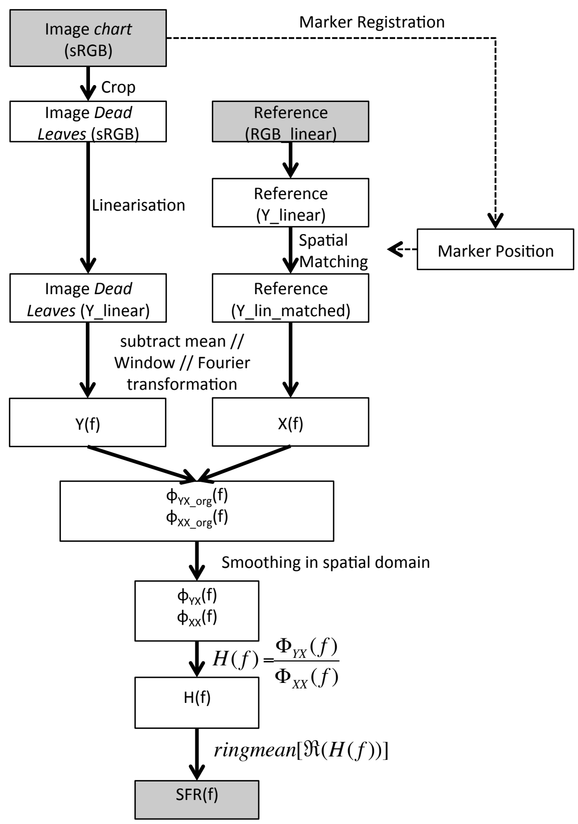

Figure 8: Flow Chart of the $SFR_{DL_{cross}}$ algorithm.

The new *cross* approach uses the cross power density $\phi_{YX}(f)$ of target and imager and the auto power density of the target $\phi_{XX}(f)$ to obtain $H(f)$ (see Eq. 5). The most critical part of this analysis is to obtain $\phi_{YX}(f)$, as we have to create a reference which represents the ideal image.

$$H(f) = \frac{\phi_{YX}(f)}{\phi_{XX}(f)} \tag{5}$$

[‡]semi-reference method: Known properties of the test target are compared to properties of the image content. No pixel-by-pixel comparison.

[§]full-reference method: Comparing the target and the image pixel by pixel, often used for evaluation of compression algorithm performance.

Starting point for creating the reference data is the vector based data of the printed target. Based on this, we have to consider that the camera might have an individual tone cure (different from the sRGB tone curve) and that geometric distortion of the lens and non-perpendicular projection on the sensor due to non perfect alignment of the target to the camera change the image content.

Using gray patches in the same target, we can linearize the image data to minimize the influence of the individual tone curve of the device under test.

To consider the geometric distortion and the projection, we have two steps. First, we use the dead leaves pattern only in a small part of the entire image field. So the test pattern shall only cover one quarter or less of the image height. Due to this restriction, we already reduce the possible negative influence, but of course do not eliminate it.

The dead leaves pattern has to be surrounded by four markers. These markers are registered in high sub-pixel accuracy. This information is used to generate a transformation matrix. The transformation matrix can then be applied to the available vector based reference data (see Fig. 10).

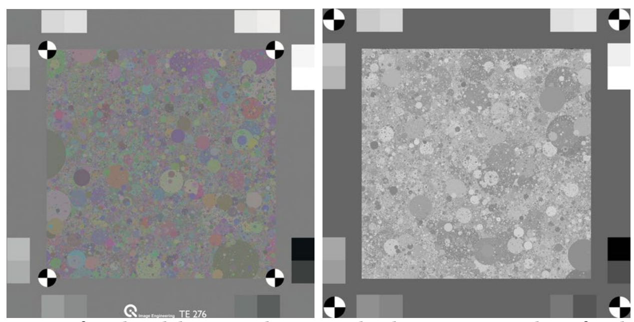

Figure 9: *right*: The gray version of a dead leaves chart with the gray patches for linearization. *left*: the colored version showing the gray patches for linearisation and registration marker for the spatial mathing.

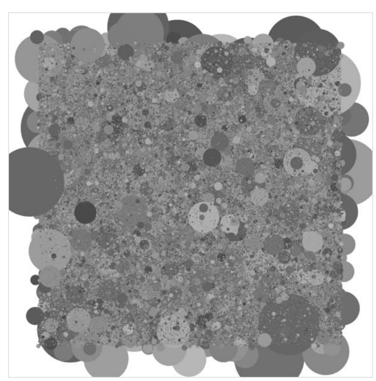

Figure 10: The vector based information of the dead leaves pattern is modified to reach projectively matching reference data to the image data. The projective transformation is based on the position of the registration marks in the four corner of the dead leaves pattern.

So the circles are shifted depending on the transformation matrix. As the spatial matching is an essential part of the algorithm, the matching is checked by comparing a high-pass filtered version of image and reference (see Fig.11). If needed, an iterative process can be applied to optimize the matching.

With the spatial matching, the cross power density of target and image can be calculated and leads to $H(f)$. A smoothing step on $\phi_{YX}(f)$ and $\phi_{XX}(f)$ is performed by applying a narrow window in the spatial domain. The SFR is finally calculated as a 1D representation of the real part of the 2D $H(f)$. The transformation from

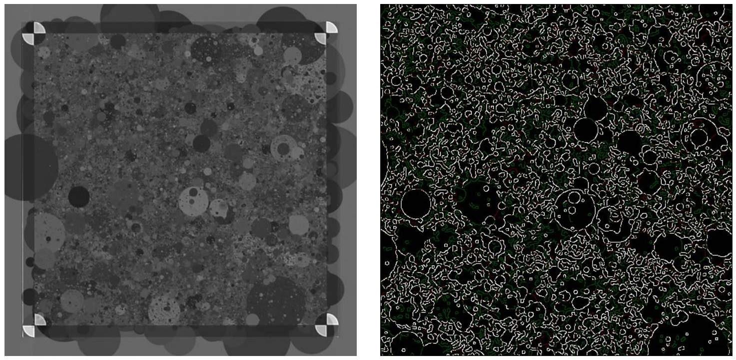

Figure 11: *left:*Matching the projectively transformed reference data to the linearized image data. Based on this data the cross power density $\phi_{YX}(f)$ is calculated. right: As the matching is a critical part of the algorithm, a check algorithm using high pass versions of the image and the reference validates the matching.

2D to 1D is performed as a so called ring-mean, which uses the average of all coefficients belonging to the same spatial frequency, regardless their orientation (a circle in the 2D spectrum).

2.3.3 artifacts

We know from our previous work, that any kind of artifacts influences the SFR resulting from the $SFR_{DL_{direct}}$ method. And we could show, that the $SFR_{DL_{cross}}$ method does not show this behavior. So from the difference of the SFR calculated using the two different methods, we can derive a metric that describes the artifacts. As numerical value, we simply calculate the difference in the the acutance of the two different methods (see Eq.6. The acutance is calculated based on a 100% view on a 96ppi screen in half meter distance.

$$artifacts = \frac{Acutance_{direct} - Acutance_{cross}}{Acutance_{cross}} \tag{6}$$

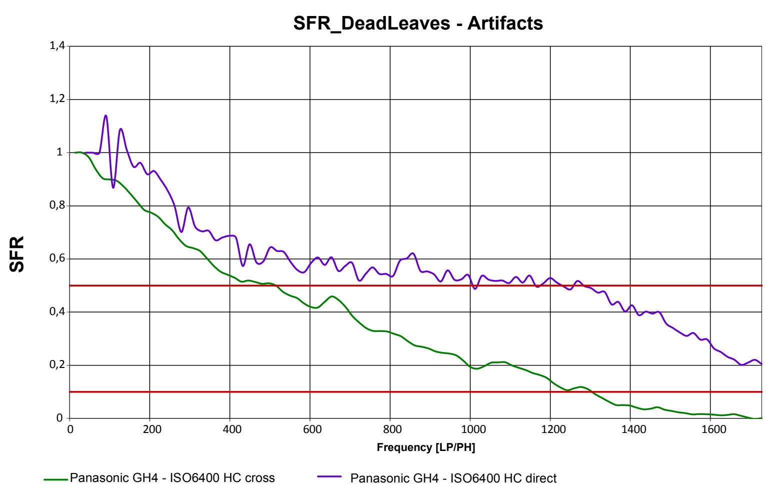

Figure 12: While the *direct* method is significantely influenced by any kind of artifacts that appear on the dead leaves pattern but not in the reference patch, the *cross* is robust against this influence. The difference between these methods is described in the metric *artifacts*.(Panasonic GH4, JPEG, ISO6400)

3. RESULTS

Our approach is to measure the SFR based on different structures and using different methods from the same image to derive useful and meaningfull objective metrics to describe the complete behavior of the camera.

To make sure, that there is no systematic error in the measurement procedure, first test is performed on an image with a minimum in non-linear signal processing. So we captured an image of the test chart (see Fig. 2) using a D-SLR in RAW mode. The resulting RAW file was then processed in very simple way using Mathworks MATLAB and its internal demosaicing algorithm.

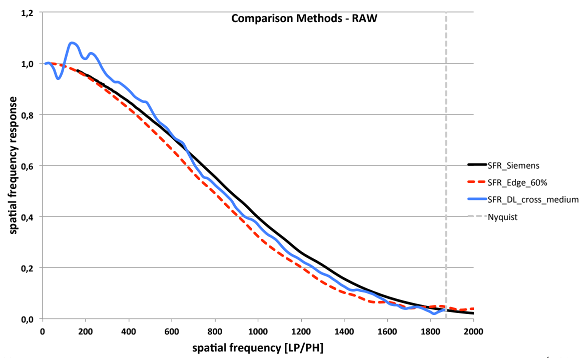

Figure 13: Comparing three different mtethods, structures in the same image.(Canon 5DMkII, RAW, ISO100,no enhancement). The differences are low. $SFR_{Siemens}$ is slightly higher compared to SFR_{Edge} as it includes the diagonal resolution.

Analyzing the file, we can see only small differences between the three different methods (see Fig.13). These can be explained by the different location of the pattern in the image field. $SFR_{Siemens}$ is slightly better than the average as it is located in the image center and includes all orientations, including the potentially higher diagonal resolution.

From this result we can see that larger differences are the result of signal processing.

Digital sharpening in the the image signal processor (ISP) has a significant on the SFR of a camera system. This process increases the contrast on lower spatial frequencies which makes the image appear "sharper" to a human observer. If there is too much sharpening applied, artifacts are introduced especially along edges the undershoot and overshoot gets visible. So for best image quality, a decent level of sharpening has to be found.

The different methods react differently on sharpening. For an evaluation, a D-SLR in JPEG mode has been used to perform a "sharpening bracketing", so images have been captured in the exact same way, only the setting for image sharpening has been changed.

Evaluating the $SFR_{Siemens}$, we can see in Figure 14 a dependency of the result on the sharpening. The SFR is significantly increased in the mid frequencies, the differences in the high spatial frequencies close to the limiting resolution is low. This is the expected behavior, as sharpening boosts the local contrast and therefore also the measured SFR. As information that is already lost can not be increased, it is also clear that the increase of the SFR in the high spatial frequencies is low.

When comparing the different methods and how they react on different level of sharpening, we see that the SFR_{Edge} approach and there especially the 80%edge is extremely increased depending on the sharpening. The maximum SFR is above 180% and also the high frequencies are increased. The results on the 60%edge are much more reasonable[¶], but also shows an increase of the SFR in the higher spatial frequencies.

For the results based on the dead leaves pattern, we see very close results on the medium and low contrast pattern, only if the sharpening is at its maximum, we see some differences in the lower frequencies. This is a special behavior of the used camera, other camera do show more significant differences. The SFR based on the

[¶]ISO12233:2014 recommends to use a 60%edge for resolution measurement.

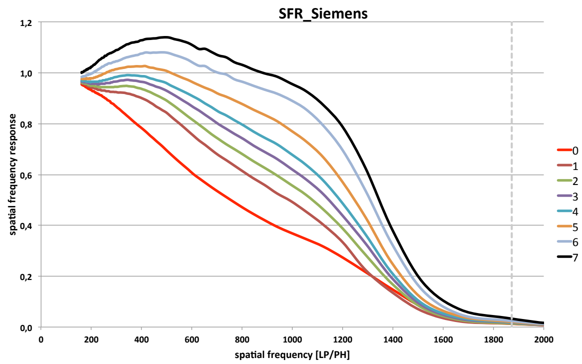

Figure 14: $SFR_{Siemens}$ of a sharpening bracketing using a Canon 5DMkII D-SLR. Lines represent different setting for Sharpening from 0 to 7 (default = 3). The results represent the characteristic of sharpening: Large difference in medium spatial frequencies, low differences in high spatial frequencies.

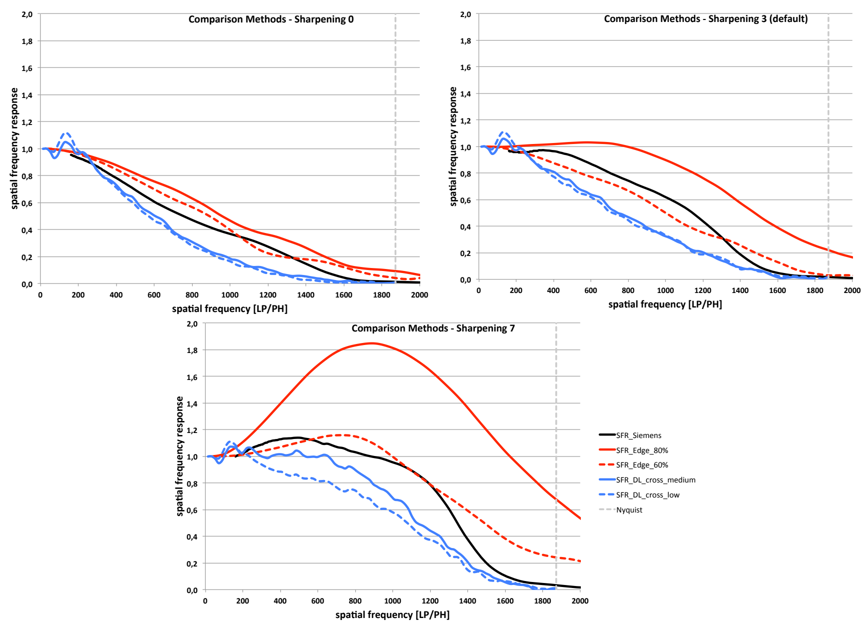

Figure 15: Direct comparison of different methods at different level of sharpening. (Canon 5DMkII, ISO100) *top left:* Sharpening = minimum (0), *top right:* Sharpening = default (3) , *bottom:* Sharpening = maximum (7)

dead leaves pattern is lower in all cases compared to the other methods. As we have seen it differently for the results on RAW, we can assume that this is due to noise reduction or other effects that lead to a lower SFR on low contrast, fine details.

The measured sharpening (as described in Section 2.2.1) of the Canon 5DMkII depends significantly on the edge contrast, the higher the contrast, the higher the sharpening. In Figure 16 we compare the behavior to a Nikon D800. We see for this camera, that the sharpening is much less influenced by the edge contrast.

The mentioned behavior of contrast dependent sharpening can also be found in the examples in figure 17 with the matching table 1.

These two cameras represent two different kind of image tuning, so the setting of parameter like sharpening, noise reduction and contrast enhancement. The Leica T shows a very defensive tuning, so the sharpening is not very high which means for some observer that the image is not sharp enough, but on the other side it does not show unpleasant denoising artifacts or significant texture loss. The Samsung NX3000 represents a camera that make intensive use of image enhancement algorithms, which makes the image appear sharper, but also introduces

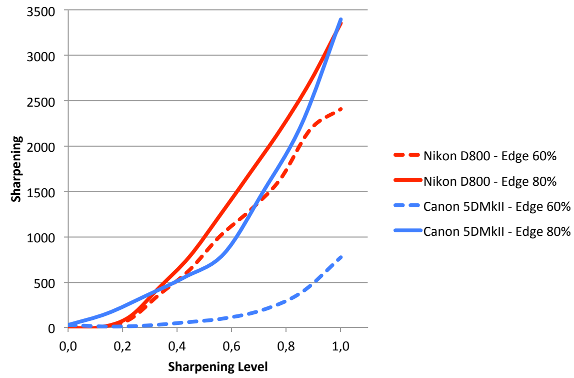

Figure 16: Sharpening vs. normalized Sharpening Level (Canon 5DMkII and Nikon D800) based on the ESF extracted from two edge contrast level (80% and 60%). The difference depending on the edge contrast is low for the Nikon, but significant for the Canon.

artifacts and texture loss. This paper is not about to decide which of these tuning decisions are better, it is about to show the difference in numerical and objective metrics.

Using the standard methods as described in ISO12233:2014 provide opposed results. Using $SFR_{Siemens}$ results in a better SFR of the Leica camera, as it has higher numerical results in all metrics. According to SFR_{Edge}(60%Edge) the Samsung camera has better numerical results. Checking the $Sharpening$ value explains this behavior. The Samsung cameras uses a significant higher amount of digital sharpening, resulting in undershoot and overshoot along edges. The observed sharpening in the Leica camera is quite low, some observer might judge this amount as too low.

The limiting resolution $MTF10$ can only be evaluated using $SFR_{Siemens}$ and $SFR_{DL_{cross}}$ as the other methods in most cases do not drop to a modulation below 10%. In this example the Leica T shows a higher limiting resolution on the Siemens star, even though is has a lower pixel count (16Megapixel vs. 20 Megapixel). This higher level of limiting resolution can also be observed in the captured images.

The differences in the numerical results based on the medium and the low contrast version of the dead leaves pattern is quite low for the Leica T, the Samsung NX3000 shows much larger differences between the contrast level. Also the total differences between different methods is much lower for the Leica. The maximum difference between all found MTF50 values on all methods and contrasts is 344LP/PH, while the Samsung has a maximum difference of 714LP/PH.

Before the new $SFR_{DL_{cross}}$ method based on two contrast level was available, we only had the $SFR_{DL_{direct}}$ method on a medium contrast pattern to evaluate the texture loss. Checking these values, the Samsung would outperform the Leica camera and based on the numerical results one would judge the texture loss of the Samsung better than for the Leica. The images shows it differently and now also the numerical results reflect this. The Samsung NX3000 drops by around 50% in MTF50 and Acutance between $SFR_{DL_{direct}}$(medium) and $SFR_{DL_{cross}}$(low), while the Leica T only drops by around 20%. This is also most likely a result of the strong sharpening which is applied to the image.

The metric *artifacts* reflects the behavior also quite well, as it is significantly higher for the Samsung compared to the Leica (37.9 to 14.0 for the low contrast pattern).

Figure 17: Detail of the used testchart to illustrate different types of camera tuning. *left:* Leica T, JPEG, ISO100, *right:* Samsung NX3000, JPEG, ISO1600;

		Samsung NX3000	**Leica T**
	Mode	JPEG	JPEG
	Settings	default	default
	ISO	1600	1600
	Height [px]	3648	3264
SFR_Siemens	MTF10	1419	1528
	MTF50	1087	1134
	Acutance	0.69	0.80
SFR_Edge 80%	MTF50	1255	1099
	Acutance	0.83	0.74
	Sharpening	1708	696
SFR_Edge 60%	MTF50	1380	1038
	Acutance	0.99	0.69
	Sharpening	1523	368
SFR_DL_direct_medium	MTF50	1396	1015
	Acutance	0.99	0.65
SFR_DL_direct_low	MTF50	1121	913
	Acutance	0.70	0.78
SFR_DL_cross_medium	MTF10	1431	1260
	MTF50	928	848
	Acutance	0.74	0.67
SFR_DL_cross_low	MTF10	1161	1225
	MTF50	682	790
	Acutance	0.52	0.61
DL_medium	Artifacts	34.5	22.0
DL_low	Artifacts	37.9	14.0

Table 1: Example data of two cameras, matching the images in Figure 17
MTF10 and MTF50 in LP/PH; Artifacts in %

4. CONCLUSION

The signal processing within a digital camera, no matter of D-SLR or smartphone camera, is very complex and in most cases adaptive to the image content. So the reproduction of spatial frequencies is non-linear and therefore a single SFR can not describe the entire system. For different aspects of spatial frequency reproduction, different methods and/or pattern are more suitable.

The maximum optical performance of a camera system is reflected in the **limiting resolution**, so the maximum spatial frequency that can be transferred. The limiting resolution is well defined in the MTF10 value. The best method to obtain the limiting resolution is the $SFR_{Siemens}$ method, as its especially in the high frequencies less influenced by sharpening (see Fig.14).

The maximum level of details has only a minor effect on the subjective **sharpness** of an image. The sharpness is more driven by the SFR in the lower/medium frequencies. The SFR_{Edge} method is suitable to evaluate the sharpness. Using different edge contrasts in the image is very useful to get a better impression of the overall image quality (see Fig.16). The exact metric and its correlation to the subjective impression should be a target of further research, even though we see that the used acutance fits the subjective evaluation of a small group of engineers and several editors of photography magazines.

Using the ESF based on several edges with different edge contrast to evaluate a metric for the **sharpening** is very useful when testing different camera systems. High numerical values or high SFR results can be explained with this value. This makes test results more meaningful, as it can be differentiated between great optical system performance and strong influence of signal processing.

While the optical performance and edge sharpness can be derived from standard methods (ISO12233:2014), the **texture loss** as loss of low contrast, fine details is still under discussions in the different standard work groups. We can see in our results, that the dead leaves pattern has its benefits and is a useful pattern. We propose to use it in at least two different level of contrast, while the low contrast level is the most important. The new approach $SFR_{DL_{cross}}$ which is based on a direct calculation of the cross power density shows its benefit, as artifacts and noise does not influence the results. This is especially important for mobile imaging.

The new metric **artifacts** as the difference between the evaluation methods on the dead leaves pattern is very useful to provide an objective measure for this issue. The higher the number, the more unpleasant artifacts are visible in the image. This should be definitely part of further evaluation to get a match with a subjective score system.

Evaluating a huge amount of different kind of cameras, we could successfully instal a ranking system for photography magazines that does not require any subjective correction in case that numerical results do not correlate with the subjective impression. This work has also be done for a huge set of mobile phone with the same positive outcome.

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