Description of texture loss using the dead leaves target: Current issues and a new intrinsic approach

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ABSTRACT

The computing power in modern digital imaging devices allows complex denoising algorithms. The negative influence of denoising on the reproduction of low contrast, fine details is also known as texture loss. Using the dead leaves structure is a common technique to describe the texture loss which is currently discussed as a standard method in workgroups of ISO and CPIQ. We present our experience using this method. Based on real camera data of several devices, we can point out where weak points in the $SFR_{DeadLeaves}$ method are and why results should be interpreted carefully. The $SFR_{DeadLeaves}$ approach follows the concept of a semi-reference method, so statistical characteristics of the target are compared to statistical characteristics in the image. In the case of $SFR_{DeadLeaves}$, the compared characteristic is the power spectrum. The biggest disadvantage of using the power spectrum is that phase information is ignored, as only the complex modulus is used. We present a new approach, our experience with it and compare it to the SFR Dead Leaves method. The new method follows the concept of a full-reference method, which is an intrinsic comparison of image data to reference data.

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

1. INTRODUCTION

Evaluating a digital camera for its image quality is a complex task, especially if the numerical results should reflect the subjective impression of a naive user. One of the biggest unsolved problems is the measurement and the description of the so called texture loss, i.e. the loss of low contrast, fine details. While some images get an watercolor-like look and lose all details, the results for spatial frequency response (SFR) and noise measurement can still be good.

While this is a serious problem for the objective evaluation, there is still no method available which fulfills all requirements for a good measurement procedure.

The most discussed approach is the so called "Dead Leaves" method. Figure 1 shows a colored version of the used test pattern. First presented within the CPIQ work group by Cao et al.,[1] it was proposed to compare the known power spectrum of the dead leaves structure with the power spectrum of the image a device produced from it. After some improvements presented by McElvain et.al.,[2] this method has been widely accepted and has got even more attention. Also Image Engineering GmbH & Co KG started to use the method in its own lab with some modifications to the target.[4] As the texture loss is an important aspect of image quality evaluation, ISO TC42 WG18 started an ad hoc group with the task to define a measurement covering this aspect. Using the dead leaves approach on a significant number of different kinds of cameras, it can be shown that the method itself may provide wrong information for the texture loss as it gets fooled by noise, denoising and/or sharpening algorithms.

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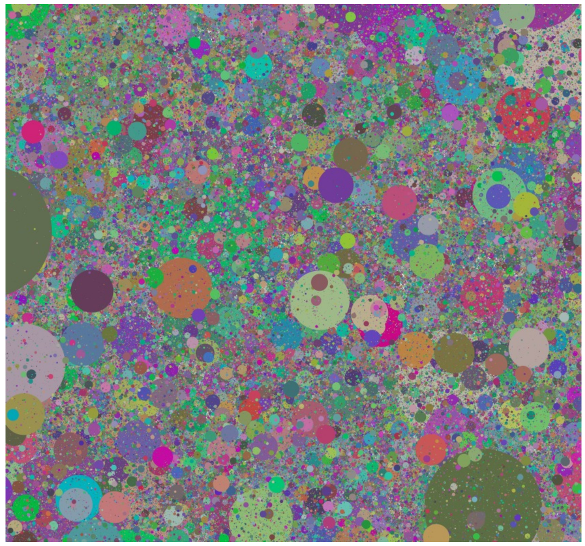

Figure 1: The colored dead leaves target

2. PROBLEM OF CURRENT APPROACH

The *ISO texture group* created a camera test chart compiling many common methods for texture and resolution evaluation so that the performance of the different methods can be compared in a single image. At the Image Engineering test laboratory more than 35 cameras were tested at all available sensitivity settings. Due to this work several examples for misleading measurements using the dead leaves method could be found. Our daily experience in our work as a test lab fore some of the most important photographic magazines in Germany fortify these results. Some of our customers found the dead leaves measure not to be reliable as in some cases results would diverge significantly from subjective image quality evaluations. For several cameras of different manufacturers, the dead leaves method provides results like the one shown in Figure 2 where the $SFR_{DeadLeaves}$ rises while the subjective impression shows a significantly decreasing image quality.

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

Taking a look at the principle of noise correction applied to the dead leaves results, as described by McElvain,[2] it is not surprising to obtain such a good result even if the image has a very high noise level. Equation 1 shows the calculation of the $SFR_{DeadLeaves}$. $PS_{image}(f)$ is the power spectrum of the image taken with the device under test of a dead leaves target. $PS_{target}(f)$ is the known power spectrum of the target itself and $PS_{noise}(f)$ is the power spectrum of an image of a noise reference gray patch with the same mean brightness as the dead leaves target. This approach can only work if the image of the noise reference is treated the same way as the image of the dead leaves chart by all signal processing applied. This would mean a colored area structured with a broad spectrum of frequencies is treated the same way as a homogenous gray area. It is common knowledge that this case is fairly improbable or close to impossible talking about consumer cameras. Modern denoising algorithms are able to treat homogenous areas quite differently than structured ones. The easiest task for such algorithms is to clear a homogenous area from noise by selectively applying a low pass filter to uniform areas in the image.

The main misguidance of the current approach is due to its limitation on data usage. The power spectrum of an image provides information about the frequencies in the image only but no spatial information is provided. So no matter where in the image a certain frequency at a certain amplitude appears it will always lead to the same power spectrum. This means that the algorithm of the current approach cannot distinguish between parts of the

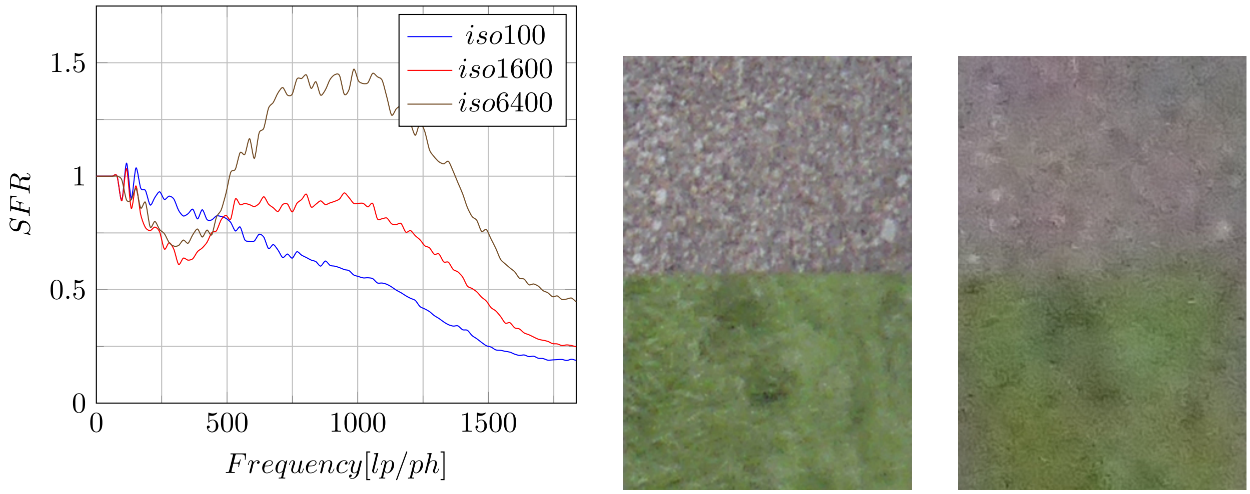

Figure 2: Panasonic Lumix DMC-TZ41
Images and results; *from left to right:* SFR Dead Leaves, ISO1600, ISO6400

power spectrum coming from original dead leaves structures and from noise or artifacts of the same frequency and amplitude.

The authors of the original dead leaves approach[7] already mentioned the malfunction of the method, but expected this problem only to be appearing at the combination of a blurry image with a very high noise level. This was considered a very improbable case but facing the sensitivity range of modern imaging devices this assumption has to be corrected. Analyzing the performance of a big range of cameras and cellphones with the *ISO texture chart* the Dead Leaves measure was found to be inconsistent with the subjective impression of texture performance for most devices at high and sometimes even medium sensitivities.

3. NEW INTRINSIC APPROACH

3.1 Signal Theory

Assuming our camera system as a linear system, we can describe the system with input $X(f)$, transfer function $H(f)$ and the output $Y(f)$ (see Eq. 2).

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

Due to the convolution theorem, the output is the product of input and transfer function (see Eq. 3).

$$Y(f) = X(f)H(f) \tag{3}$$

The power spectrum of the output ϕ_{YY} is calculated from the amplitude response $|H(f)|^2$ and the power spectrum of the input ϕ_{XX} (see Eq. 4) where $E[|Y(f)|^2]$ is the expected value of the amplitude of the output signal.

$$\phi_{YY}(f) = E[|Y(f)|^2] = E[|H(f)|^2|X(f)|^2] = |H(f)|^2\phi_{XX}(f) \tag{4}$$

So we can directly calculate the amplitude response $|H(f)|$ using the power spectrum of input and output as shown in equation 5.

$$|H(f)| = \sqrt{\frac{\phi_{YY}(f)}{\phi_{XX}(f)}} \tag{5}$$

This is basically the original dead leaves approach as shown in equation 1. As described in section 2, spatial information is needed to avoid misguiding values due to noise and artifacts in images. Spatial information in an image-like signal is represented by the phase and as shown in equation 4, the phase information is lost as only the modulus is taken into account.

So the aim is to find a way to obtain the full transfer function $H(f)$ including the phase information instead of just the power spectrum $|H(f)|^2$.

We are using the cross correlation power density $\phi_{YX}(f)$ between the input and output signal (see 6).

$$\begin{aligned} \phi_{YX}(f) &= Cov(Y(f), X(f)) = E[Y(f)X(f)^*] \\ &= E[H(f)X(f)X(f)^*] = H(f)E[|X(f)|^2] = H(f)\phi_{XX}(f) \end{aligned} \tag{6}$$

So we can directly calculate $H(f)$ using the cross power density $\phi_{YX}(f)$ and the auto power density $\phi_{XX}(f)$:

$$H(f) = \frac{\phi_{YX}(f)}{\phi_{XX}(f)} \tag{7}$$

So by using the cross correlation, we can calculate $H(f)$ with full amplitude and phase information.

3.2 Implementation

For an implementation in imaging, we assume $Y(f)$ as the resulting spectrum of image for the system under test. $H(f)$ is the transfer function we want to use to describe the camera system. As we are now looking for the full transfer function, we need to change the approach from a semi-reference method to a full-reference method. This is why the biggest challenge is to get $X(f)$, i.e. the input signal.

We assume a controlled lab environment where the camera under test reproduces a known test target. As the dead leaves pattern is known to show the texture loss problems, but only the analysis approach behind it fails, we chose to also use the dead leaves pattern for the new approach. Instead of only using the power spectrum of the pattern, we use the full spatial information based on the original data that was used to generate the test target.

The dead leaves test target is available in linear RGB data, the image data is available in an output gamma corrected color space (most likely sRGB). The image data is linearized using the tone curve information of the output color space and reduced to a single luma channel Y. Also the reference data is reduced to a single luma channel Y.

The pattern will only cover a small part of the full image plane, so we can neglect the local influence of geometric distortion within the pattern. Registration of the to the measured pixel pattern and the original target can be achieved using projective transformation based on the position of markers around the dead leaves pattern. The spatial matching process is important and can have significant influence on the later results. After the spatial matching, the image and the reference show the same image content except for the influence of the camera regarding spatial frequency transfer, added noise, and noise reduction artifacts.

Based on the image data and the reference data, the signals $Y(f)$ and $X(f)$ (cf. Eq. 2) are calculated using the Fourier transformation on the mean-corrected and windowed 2-D data.

Based on $Y(f)$ and $X(f)$, the cross power density $\phi_{YX}(f)$ and the auto power density $\phi_{XX}(f)$ are calculated. For smoothing, these are transferred into the spatial domain, windowed and transferred back into the frequency domain before the quotient is calculated. The quotient of $\phi_{YX}(f)$ and $\phi_{XX}(f)$ is $H(f)$, which is complex and two dimensional. The final reported SFR is the 1-D representation of the real part of H(f). To go from 2D to 1D, the average of all spectral coefficients of the same frequency modulus $\|f\|$ is calculated.

The flow chart in Figure 3 visualizes all calculation steps.

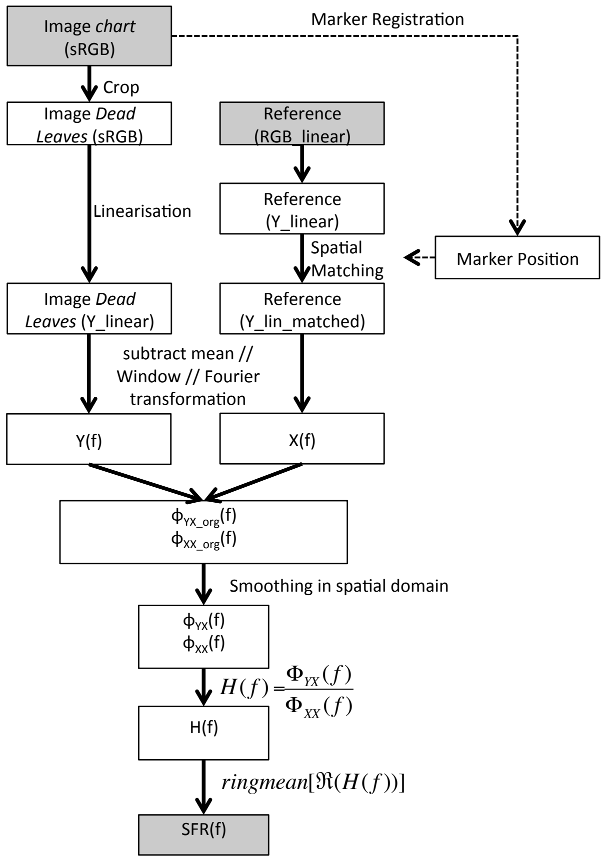

Figure 3: Flow Chart

4. RESULTS

Several cameras of different types (D-SLR, compact, cell phone) were used for our tests. The device under test had to reproduce a test target showing the dead leaves structure. The scene was illuminated with D65 fluorescent light sources at around 1000 lux. The devices were set to automatic mode, while the ISO speed was manually selected. We took several images at different sensitivity settings, starting from ISO100 up to maximum available setting. All images were analyzed using the current approach based on the power spectrum and with the new intrinsic approach as presented in section 3.

Our results show that the different approaches lead to significant differences in the resulting SFR. For all measurements the SFR of the new intrinsic approach is below the SFR of the power spectrum approach. The higher the noise level in the images and the more artifacts the images show, the more significant the differences. In several cases, the old approach fails to describe significant deficiencies in the image, while the new approach reflects the visual impression of texture loss.

With the new intrinsic approach, images that lead to misleading results using the power spectrum approach (see section 2), provide results meeting the expectation from the subjective evaluation. Image quality degrades with increasing ISO speed and so does the SFR.

In this paper, we present several examples of different cameras reflecting our overall experience.

The results of the compact camera Panasonic Lumix DMC-TZ41 are shown in Figure 4. The high noise level in the captured images mislead the power spectrum approach and the SFRs do not reflect the visual impression.

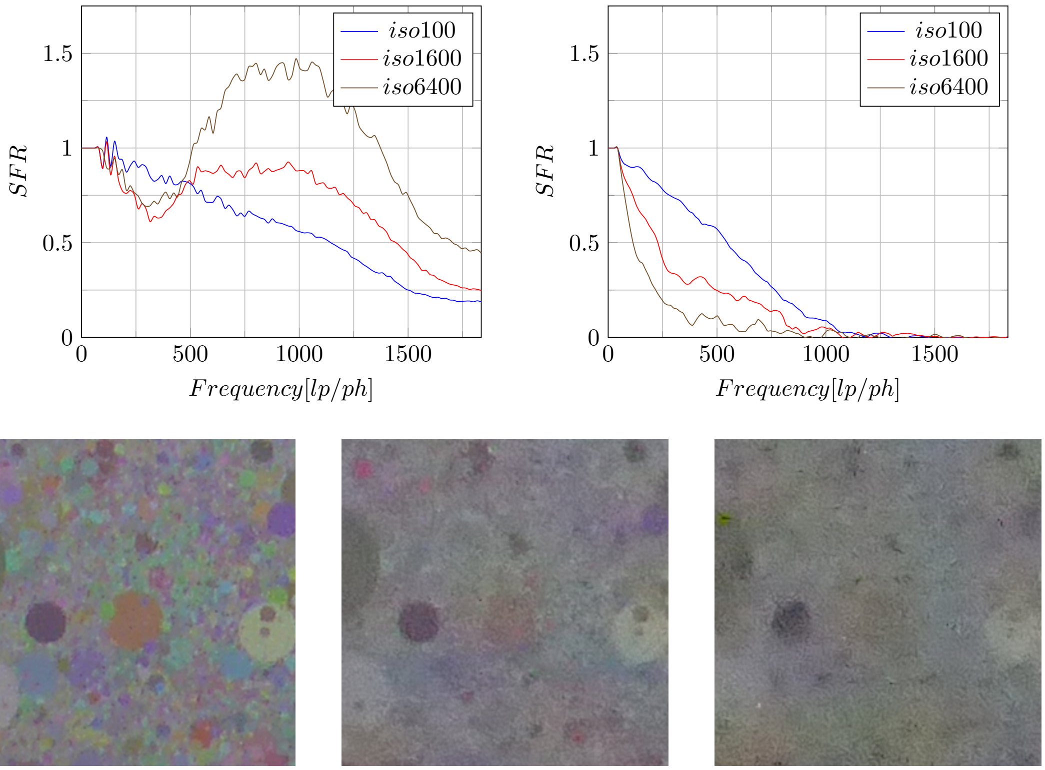

Figure 4: Panasonic Lumix DMC-TZ41
Comparison of SFR; *top left:* current approach, *top right:* new intrinsic approach
Dead Leaves images; *bottom from left to right:* ISO100, ISO1600, ISO6400

With the new approach, we meet the expected results, as ISO6400 provides the worst SFR ISO100 provides the best result.

Another good example for misleading results of the old approach is the Samsung Galaxy S4 Zoom as shown in Figure 5. The artifacts added to the image at all ISO speed settings added frequency content to the power spectrum which results in very low differences in the SFR of different ISO speed settings. With the new intrinsic approach, we clearly see differences that match the subjective impression very well.

For the purpose of numerical comparison the SFR is reduced to a single MTF50 value (see Figure 6). The MTF50 value is the highest spatial frequency that results in a spatial frequency response of $\leq 50\%$. The unit is line pairs per picture height. We see that with the current approach, the numbers sometimes even increase with increasing ISO speed, which is against the visual impression on the images. With the new approach, the numbers decrease with increasing ISO speed as expected.

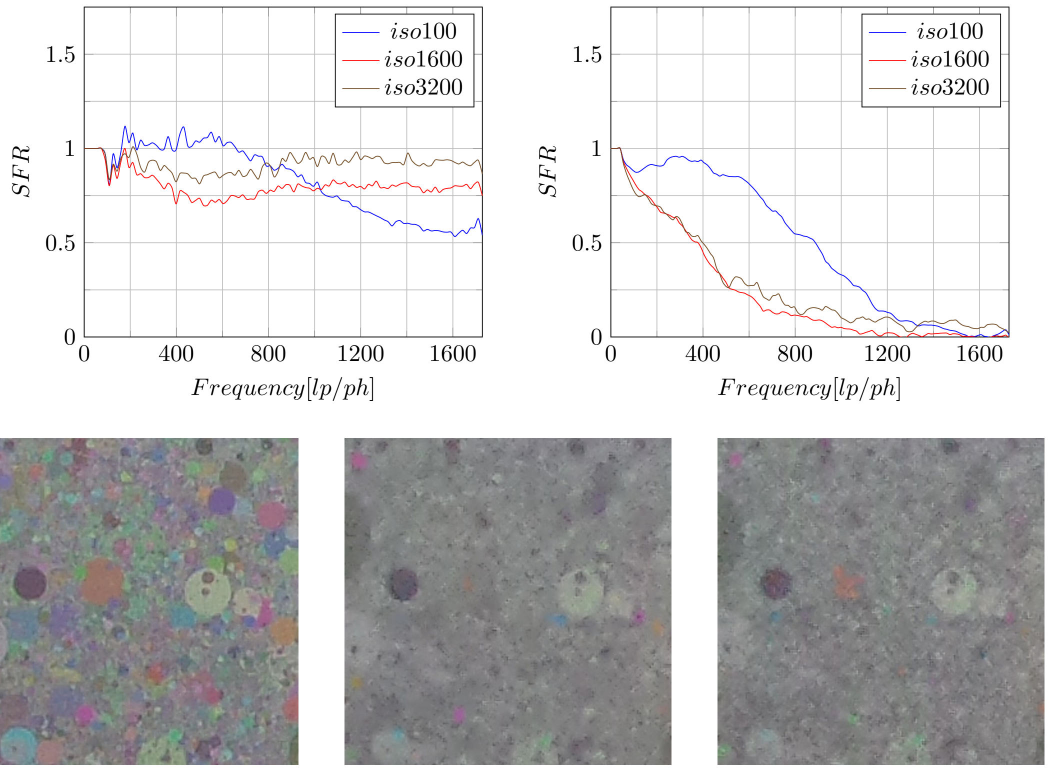

Figure 5: Samsung Galaxy S4 Zoom
Comparison of SFR; *top left:* current approach, *top right:* new intrinsic approach
Dead Leaves images; *bottom from left to right:* ISO100, ISO1600, ISO3200

MTF50		current approach [lp/ph]	new approach [lp/ph]
Canon EOS 5D Mark III	ISO100	1434	1294
Canon EOS 5D Mark III	ISO1600	1395	1061
Canon EOS 5D Mark III	ISO25600	1433	311
Nikon Coolpix S9500	ISO125	894	608
Nikon Coolpix S9500	ISO1600	434	236
Nikon Coolpix S9500	ISO3200	285	175
Panasonic DMC-TZ41	ISO100	1145	546
Panasonic DMC-TZ41	ISO1600	1444	228
Panasonic DMC-TZ41	ISO6400	1705	114
Samsung Galaxy S4 Zoom	ISO100	n/a	887
Samsung Galaxy S4 Zoom	ISO1600	n/a	378
Samsung Galaxy S4 Zoom	ISO3200	n/a	399
Sony Alpha 77	ISO100	1238	914
Sony Alpha 77	ISO1600	1095	648
Sony Alpha 77	ISO12800	1429	239

Figure 6: Table of measurement results; (n/a): Calculation not possible

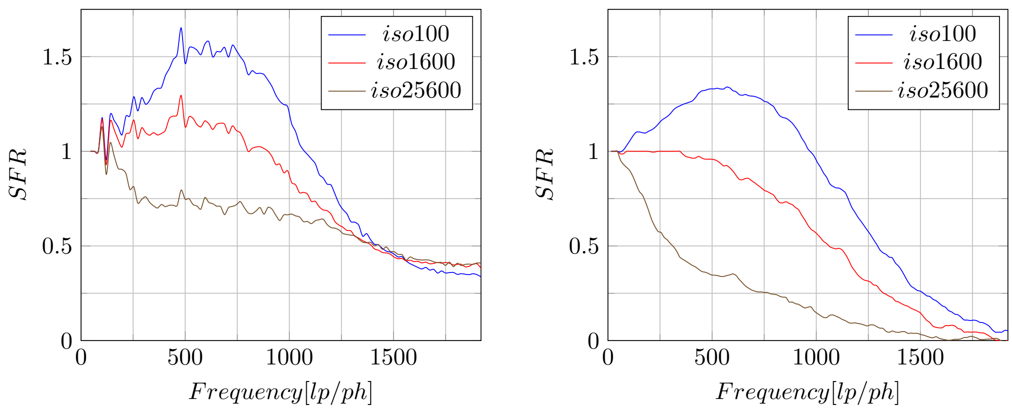

Figure 7: Canon EOS 5D Mark III - comparison of SFR.
left: current approach, *right:* new intrinsic approach

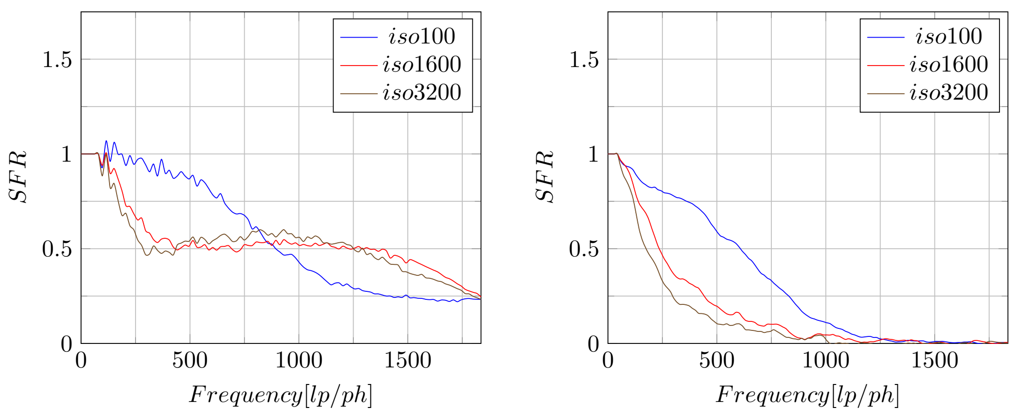

Figure 8: Nikon Coolpix S9500 - comparison of SFR.
left: current approach, *right:* new intrinsic approach

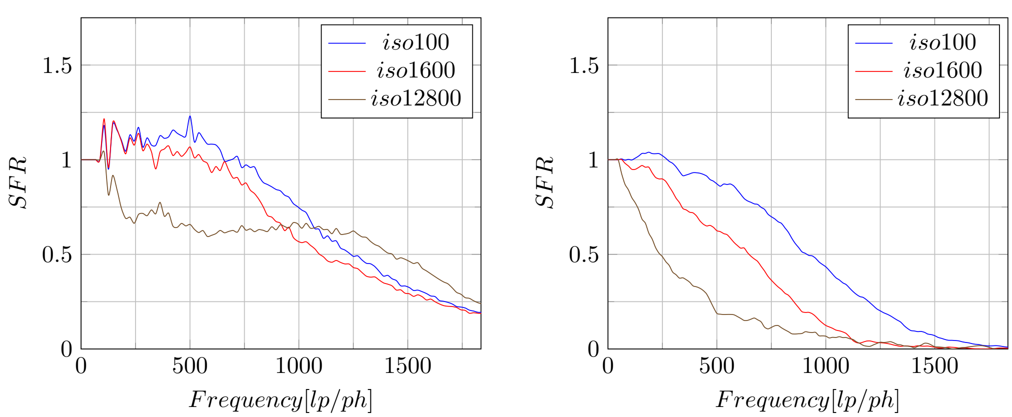

Figure 9: Sony Alpha 77 - comparison of SFR.
left: current approach, *right:* new intrinsic approach

5. CONCLUSIONS AND FUTURE WORK

Due to the work in the *ISO texture group* and our experience as a test laboratory, we found the current approach of the Dead Leaves measurement leading to misguiding results in some cases, especially when testing compact and cellphone cameras. In these cases, the Dead Leaves results were incoherent with the subjective evaluation of image quality. Analyzing the current Dead Leaves measure principle, we assume the reason for misleading values to be the different processing that is applied to structured image areas in contrast to homogenous ones by image enhancement algorithms on the one hand, and the limitation to spectral power values without taking spatial image information into account on the other hand.

This led to the development of our new approach as an intrinsic full-reference method. Taking into account both spectral components of the image, viz. amplitude and phase, we could design an algorithm that calculates the full transfer function from target to image. As the image phase information is kept, this method takes all available spatial image information into account.

First tests prove this method to lead to much more reliable and accurate results than the old Dead Leaves approach.

To evaluate the presented method and the coherence of the results it provides with subjective image quality, we believe that a psychophysical study on texture loss and image quality is a constructive approach. We are already working on such a study based on an online consumer survey using the *online soft copy ruler method* as presented by Burns et al.[8] Furthermore, we will apply the new method alongside our everyday camera testing to gather as much reference data as possible.

Once a stable and reliable version of the presented method is designed, the next step will be to find the most meaningful way to interpret its results. A single number output to determine a device performance with respect to texture reproduction with a good correlation to perceived image quality is the goal.

We are confident that the new approach can improve texture loss measurement significantly. In future work, we want to use this approach also to improve the noise measurement procedures as we might be able to measure noise also in structured areas and compare the results with those obtained in homogeneous patches that are used right now.

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