White paper

Image Engineering digital camera tests

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1 MEASURING THE CHARACTERISTICS

In order to anticipate a major aspect: measuring specific image quality aspects helps a lot in characterizing a camera but these measurements always have to be related to the real world images and there are numerous aspects which we will never be able to measure. So it is impossible to completely test a camera without taking pictures of natural scenes.
We at Image Engineering based our measurement procedures on the ISO standards [1, 2, 3, 4, 5, 6], which were already on their way at the time we built up the first test stand in 1997, and which served as a good starting point.
In order to get a sufficient characterization of a digital camera, a couple of characteristic values seem to be mandatory and others may be recommended or optional. The two characteristics which seem to be most important are to measure the OECF [2] (opto electronic conversion function) and the resolution [5] but a few others belong to this group as well.

The following aspects are mandatory: • OECF • White balancing • Dynamic range (related scene contrast) • Used digital values • Noise, signal to noise ratio • Resolution (limiting resolution center, corner) • Sharpness Recommended values are: • Distortion • Shading / vignetting • Chromatic aberration • Color reproduction quality • Unsharp masking • Shutter lag • Aliasing artifacts • Compression rates • Exposure and exposure time accuracy and constancy • ISO speed	Optional values may be: • View angle, zoom range (at infinity and shorter distances) • Hot pixels • Detailed macro mode testing (shortest shooting distance, max. scale, distortion) • Flash capabilities (uniformity, guiding number, light source etc.) • Startup time • Image frequency • Video capabilities (pixel count, resolution, frame rate, low light behavior) • MMS capabilities for mobile phone cameras (Resolution, frame rate, compression etc.) • Display (refresh rates, geometric accuracy, color accuracy, gamut, contrast, brightness, visibility in sunlight) • Optical stabilization • Auto focus accuracy and constancy • Metadata (Exif, IPTC) • Watermarking • Spectral sensitivities • Bit depth of raw data • Power consumption • Battery life • Detailed noise analysis • Color resolution

2 CAMERA SETTINGS

The measured values are influenced by the settings of the camera. To ensure the correct interpretation of the data, it is necessary to mention the proposed settings. Two different ways are used among testers to ensure for the correct settings:

- One uses the predefined factory settings because most users do not change these settings and they should be carefully selected by the manufacturer.
- The other way is to select settings which provide an optimum image quality.

Both ways can, but do not necessarily lead, to the same settings. For example, the manufacturer may choose a high compression JPEG file format as the standard format to ensure high speed image storage and minimum file sizes. The compression leads to an image quality which may not be the optimum image quality of the camera and therefore leads to different results. For the proposed test procedure we chose the settings mentioned in the table below to maximize the image quality provided by the camera. For all aspects which are not explicitly mentioned the default factory settings are used.

If it is possible to adjust the parameters we propose the following settings:

Parameter	**Intention**
Sensitivity	ISO 100 as the lowest typical sensitivity to minimize noise and ISO 400, if provided by the camera, to get an idea how the camera behaves at higher sensitivity levels.
File format	For OECF measurement, a file format which stores uncompressed data is preferred to avoid compression artifacts and the possible impact of the compression algorithm on the camera's noise. For all other aspects, JPEG in highest quality shall be used.
Resolution	Maximum sample rate is used which shows as many details as possible.
White balancing	Auto White balancing to avoid color casts and to see if the auto balancing works well.
Sharpening	Sharpening shall be the default value selected by the manufacturer because of the trade-off between noise and contrast/resolution.
Contrast / Gamma	Standard contrast setting shall be selected. Only in a few cases, the contrast may be varied to achieve the maximum dynamic range.
Color	The color setting which is optimized to achieve the best color reproduction of the original. If not available use default.
Flash	Generally the flash is switched off. It may be switched on only for those situations where it is explicitly needed.
Macro	The macro setting is needed only for the determination of the maximum scaling.
Focus	Usually the autofocus is activated to get sharp images.

The image transfer from the camera / camera phone to the PC will depend on the existing interfaces. The tester shall check for the interfaces in the following order and use the first one which is available for the test candidate.

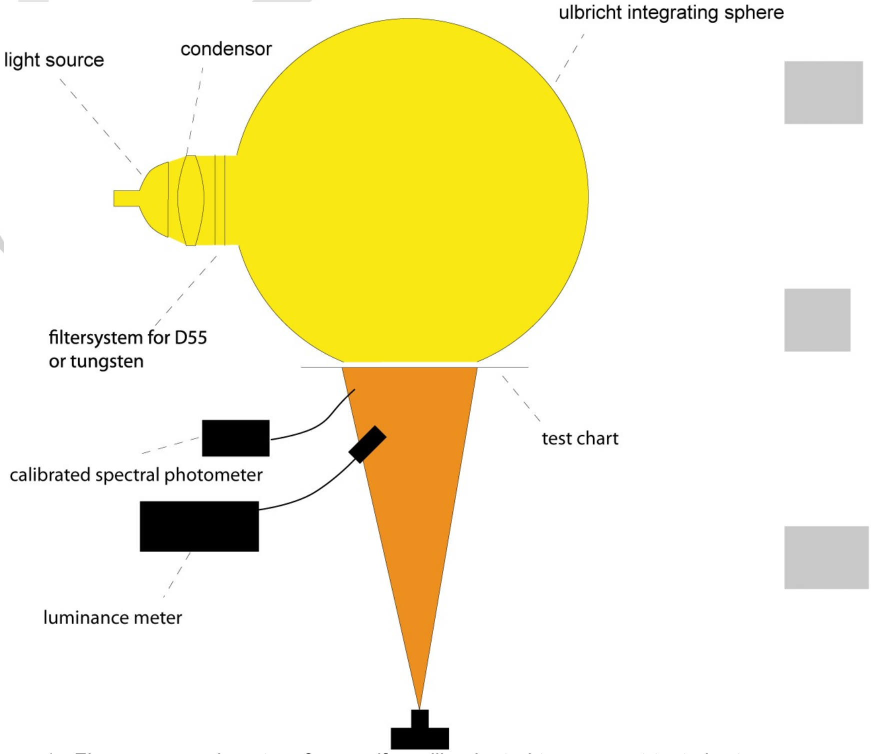
1. Memory-Card / Card Reader
2. USB
3. Bluetooth
4. Irda
5. MMS

3 TEST CONDITIONS

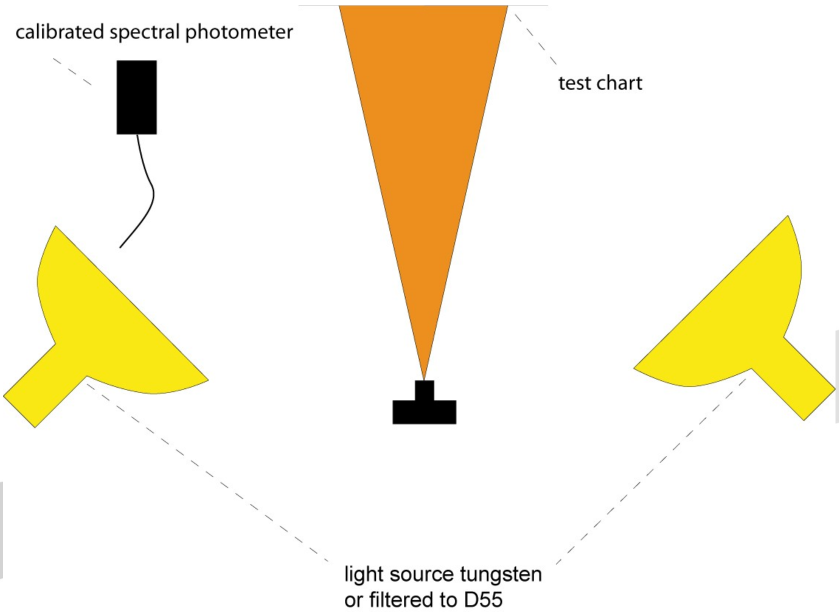
The test conditions should be set up in a way that they represent the typical conditions present in the real world use of the camera. If the camera is tested in a mode unusual for the specific application or under unusual conditions, the result may not represent the real image quality achievable for this application. If an application specific setup is used it shall be described in the test report.

The setup should fulfill the following requirements:

- Check the factory or standard settings of the camera for plausibility (sharpening, contrast, speed, saturation, white balancing) with specific care for reproducibility.
- Uniform illumination of the test chart: the use of an Ulbricht integrating sphere (app. 98% uniformity) is recommended for all measurements which require uniformity, if a light box is used the non uniformity has to be compensated by a calibration image.
- For photographic applications, color temperature and spectral distribution has to fit the requirements of ISO 7589[1].
- For photographic applications, the exposure value[4] for the OECF and color measurements should be EV7 or higher.
- Test charts for resolution, distortion, and chromatic aberration measurements should be at least 40 x 60 cm or bigger. For reflective test charts a typical reprographic daylight illumination shall be used.
- Temperature should be 23°C +/- 2°C and relative humidity should be 50% +/- 20%.
- For visual inspection and comparison, a calibrated and profiled monitor is required.
- If results are required for different lighting conditions, these conditions should be typical and the lighting conditions have to be specified.



1. *Figure: a sample set up for a uniform illuminated transparent test chart.*



2. Figure: a sample set up for a uniform illuminated reflective test chart.

4 OECF MEASUREMENTS

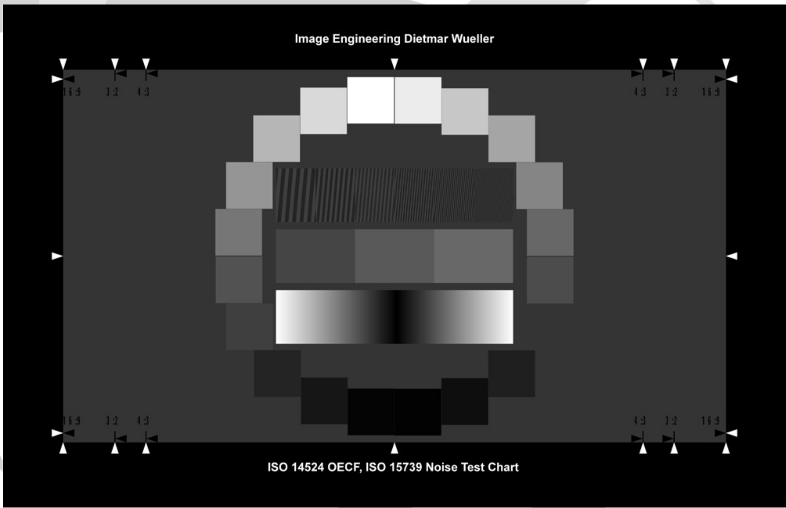
(Software used: IE Analyzer + Excel Spreadsheet)

The OECF describes how the camera transfers the illumination on the sensor into digital values in the image. This information or at least the images of the test chart are necessary to answer the following questions:

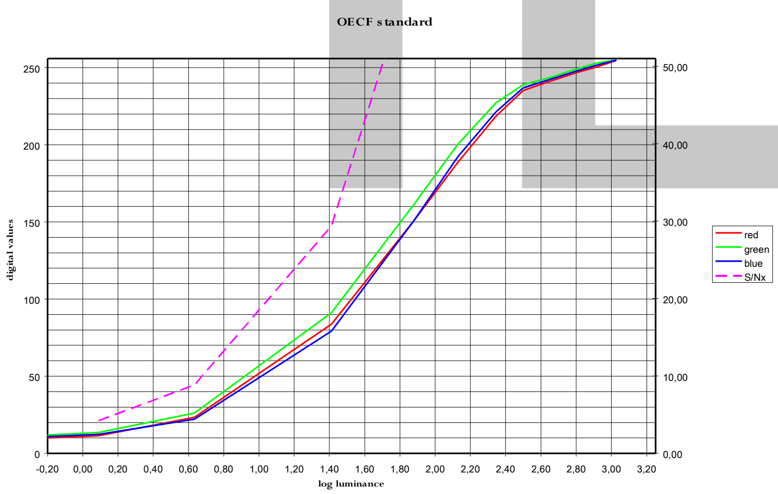
- What is the maximum contrast in a scene that can be captured by the camera in all its tonal details (dynamic range)?
- Is the white balancing o.k.?
- Does the camera use all possible digital values in the image?
- Is there a gamma or tonal correction applied to the captured linear image?
- What is the signal to noise value for different grey levels?
- What is the ISO speed of the camera?

A picture of a single chart answers all these questions.

The camera OECF (opto electronic conversion function), as specified in ISO 14524 ², is measured using a test chart with patches of different grey levels aligned in a circle around the center.



3. Figure: The OECF chart of ISO 14524 combined with the noise patches of ISO 15739. This is a special version with 20 grey levels and a contrast of 10,000:1.



4. Figure: A sample OECF curve for a camera with a high dynamic range.

4.1 Dynamic range

(Software used: IE Analyzer + Excel Spreadsheet)

The dynamic range describes the contrast in a scene the digital camera is able to reproduce.
It is determined from the OECF. In order to measure the dynamic range, the lightest point is chosen at the illumination level where the camera reaches its maximum output value. The darkest point is the illumination level where the signal to noise level passes the value of 3. The dynamic range is the contrast between the lightest and the darkest point given in contrast, f-stops or densities.
ISO 15739 defines the dynamic range on the basis of a signal to noise level of 1. According to our experience, this definition causes problems with cameras which have a flat curve in the dark areas.

In order to measure the dynamic range of a digital camera, a test chart is required consisting of a contrast which exceeds the dynamic range of the camera. Since current cameras have a high dynamic range, the 12 grey patches defined in ISO 14524[2] are not enough to get the required information, especially in the dark areas. Therefore, we have designed a chart consisting of a contrast of 10,000:1 distributed over 20 grey patches. Since the ISO standard requires a spectrally neutral chart, the preferred material to create the chart is silver halide line film with a screening to achieve the required grey density. Since the screening may lead to increased noise levels or artifacts in the images of high resolution cameras, the chart should fit an appropriate image height and the cameras may, in contrast to the procedure defined in the standard, be slightly defocused.

4.2 Used digital values

(Software used: IE Analyzer + Excel Spreadsheet)

The OECF curve should start at the digital value of 0 and go up to 255 to utilize the complete contrast available in an 8 Bit image.

4.3 White balancing

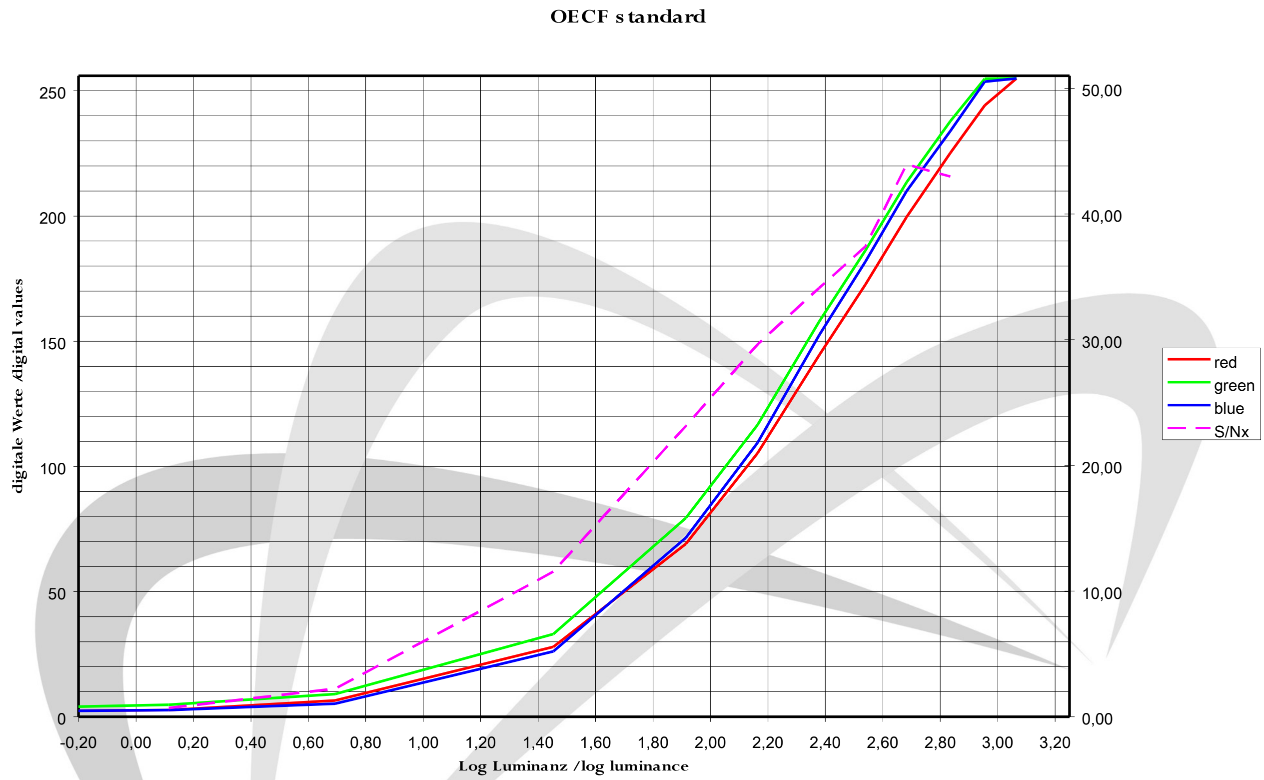
(Software used: IE Analyzer + Excel Spreadsheet)

If the automatic white balancing works well, the curves for the 3 channels should lie on top of each other. If the average difference is greater than 5 digital values, the images show a visible color cast. For OECFs determined under tungsten light, a slight color cast should remain in the image to keep the atmosphere[7].

In order to make sure that white balancing works under different lighting conditions, the grey patches of a Gretag Macbeth Color Checker SG image taken with the camera shall also be used to determine the quality of white balancing. In order to check this, the saturation shall be calculated from the a and b coordinates of the Lab values for these patches using the formula

$$C = \sqrt{a^2 + b^2}$$

For a perfect white balance, C should be 0.



5. *The white balancing of this camera leads to a green to Cyan color cast as the OECF indicates.*

4.4 Noise and ISO speed

(Software used: IE Analyzer + Excel Spreadsheet)

From the exposure data and the luminance level where the camera reaches the clipping, the ISO saturation speed value can be calculated as given in ISO 12232[4]. For the noise related speed values, the signal to noise level has to be calculated for each patch first. The software we use to do this was a Photoshop plug-in and is now a stand-alone software program in combination with an Excel spreadsheet.

In order to minimize the expense on testing cameras, we combined the two test charts for OECF and noise measurements [6] into a single high contrast chart keeping the densities of the noise patches as given in annex A of ISO 15739. The ISO total noise values are determined by our software program and a signal to noise ratio is given as an average of the three centered patches in the chart (Figure 3).

4.5 Detailed noise analysis

We can determine the noise as standard deviation for uniform areas in an image. This does not always represent the visual noise and it only takes the luminance part into account. Therefore we currently test the visual noise approach mentioned in ISO 15739 and as an alternative the sCIELAB space introduced by Zhang and Wandell[17].

These tests are part of a diploma thesis at the University of applied science Cologne and a phd study of Dietmar Wueller.

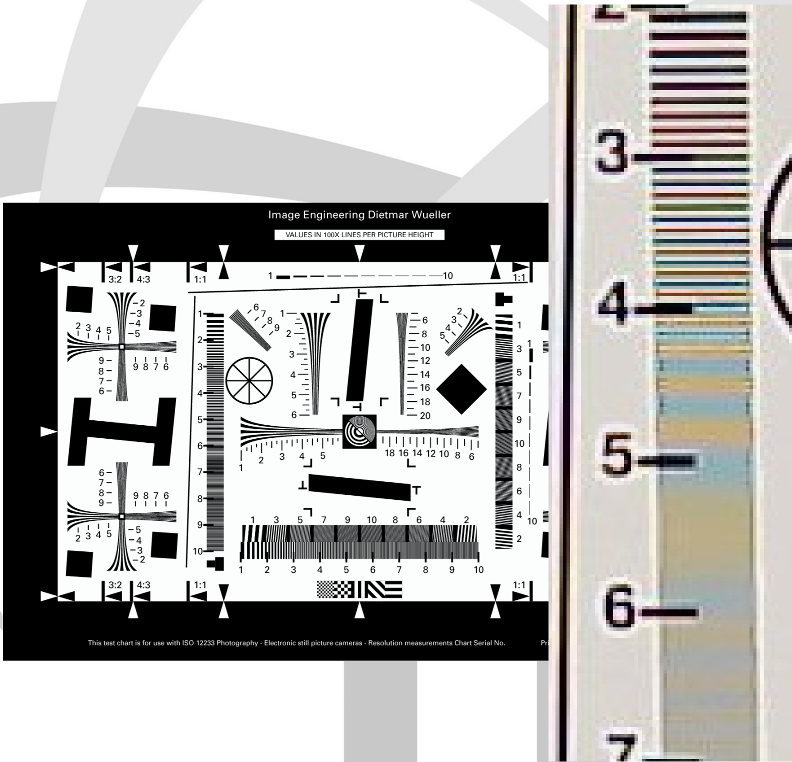
So the work is still in progress.

5 RESOLUTION

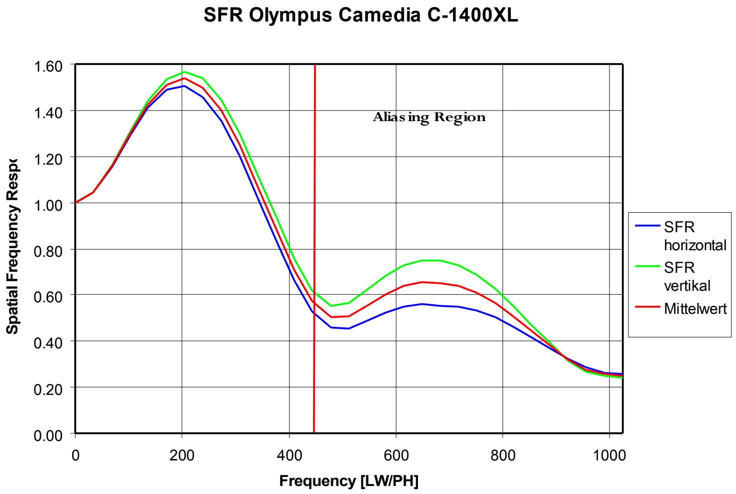
(Software used: IE Resolution + Excel Spreadsheet (recommended), or CIPA/Olympus, or SFR)

Unfortunately people think resolution to be the same as pixel count and, in fact, the pixel count as the sample rate is a limiting factor for resolution. With increasing pixel count, the other parts of the imaging system are more and more the bottle neck for the resolution, i.e. the ability of a camera to capture fine detail, especially because the manufacturers try to keep the sensor size as small as possible.

Since the beginning of our camera testing, we always had problems measuring the resolution of digital cameras. We started with visual analysis and ran into the problems described in Figure 4. Then we tried the slanted edge analysis with the SFR algorithm as defined in ISO 12233 [5, 10, 11], and found that it does not represent the resolution of a camera if sharpening or other image processing algorithms are applied to the edges in the image.



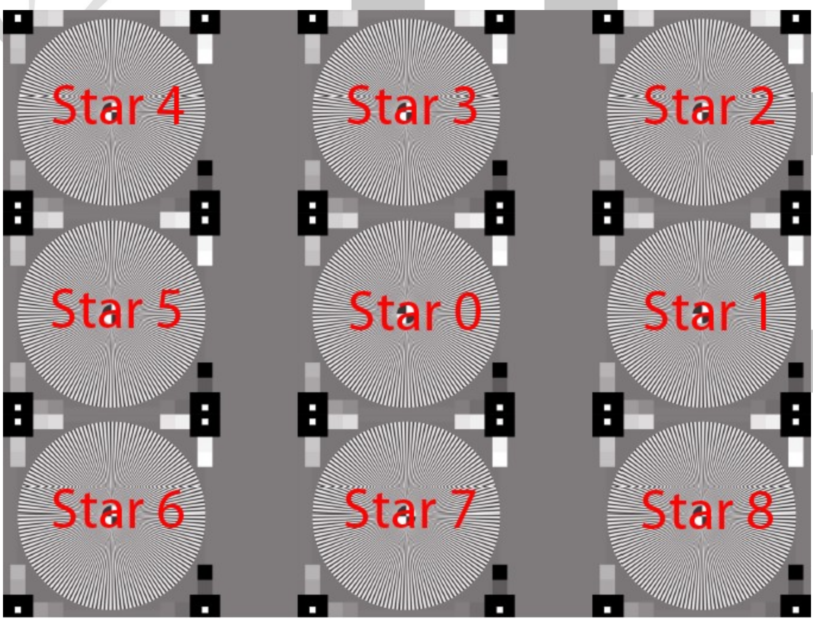
6. Figure: visual analysis of limiting resolution is often not as easy as we expect it to be



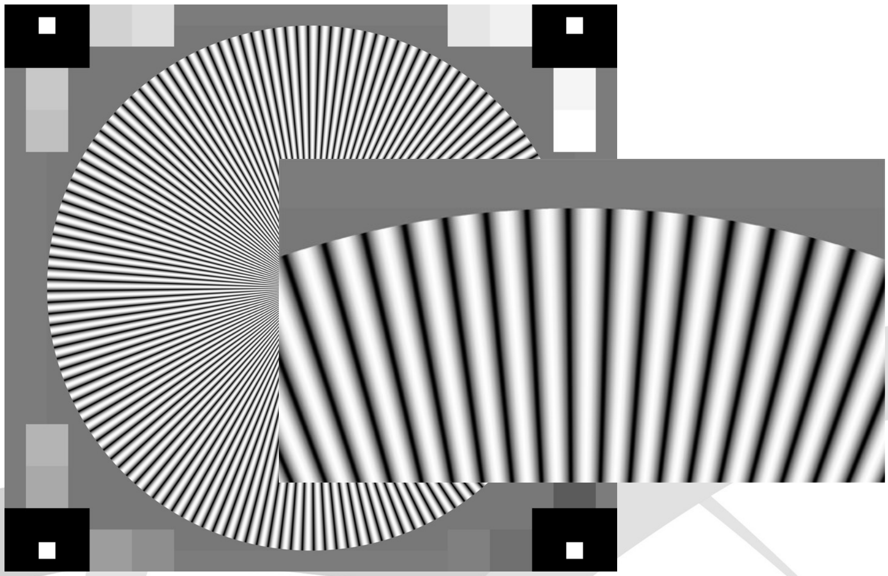
7. Figure: This SFR shows the correct analysis of the slanted edge but it does not represent the MTF of the system.

A possibility in determining visual resolution, using a more reliable analysis than a human observer, is a software developed by Mr. Hideaki Yoshida from Olympus. The software uses the ISO 12233 resolution chart (Figure on page 11) and is downloadable from the CIPA website (http://www.cipa.jp/dcs/hyres/hyres_1_e.html). This software program only determines the limiting resolution of the hyperbolic structures in the chart. In order to determine the limiting resolution at different positions in the image or to determine the sharpness equal to the contrast at low frequencies, a different method has to be used.

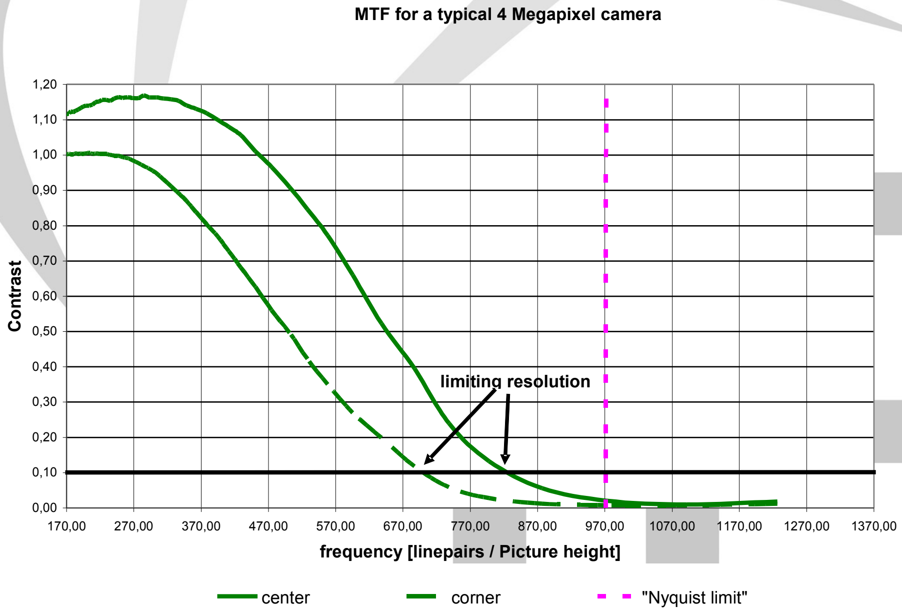
Therefore ISO technical committee 42 working group 18 discusses the implementation of another method using a test chart with 9 modulated Siemens Stars distributed over the image. A detailed description of this method and a free program software can be found in the download area on the Image Engineering website.[4]



8. Figure: The location of the 9 modulated Siemens stars.



9. *Figure: Each star has a modulation which is sine shaped in reflection and surrounding grey patches to linearize the data.*



10.*Figure: The MTF for a typical camera with the limiting resolution at 10% contrast*

From the 9 stars including 8 segments per star 72 MTF curves can be derived. These curves contain a lot of information about sharpness and resolution at the various positions and orientations. They can be used to check the optical centering of the system, to analyse optical errors like astigmatism to verify orientation specific or frequency specific image processing and to determine the limiting resolution.

5.1 Limiting resolution

(Software used: IE Resolution + Excel Spreadsheet)
Based on the Rayleigh criterion (Lord John William Strutt Rayleigh, circa 1879) the limiting resolution is defined as the frequency where the contrast reaches the level of 10%. The tests on visual resolution performed in our Lab as well as tests from Williams and Burns at the Kodak research Labs (presented at an

ISO standards meeting in Stockholm 2004) and from Matherson at Hewlett Packard correlate with Rayleigh's observations.
The limiting resolution can be determined for each of the 72 MTFs. To avoid confusion the limiting resolution shall be presented in one of the three ways:

1. as a spider diagramm for the different orientations of a single star
2. as a value for each of the 9 stars determined from an averaged MTF over all segments of each star.
3. As a single value averaged over all 9 stars. If a weighting for the differnt values is applied it should be reported together with the results.

For a zoom lens, the values shall be reported for Tele, Wide angle, and standard zoom position separately.

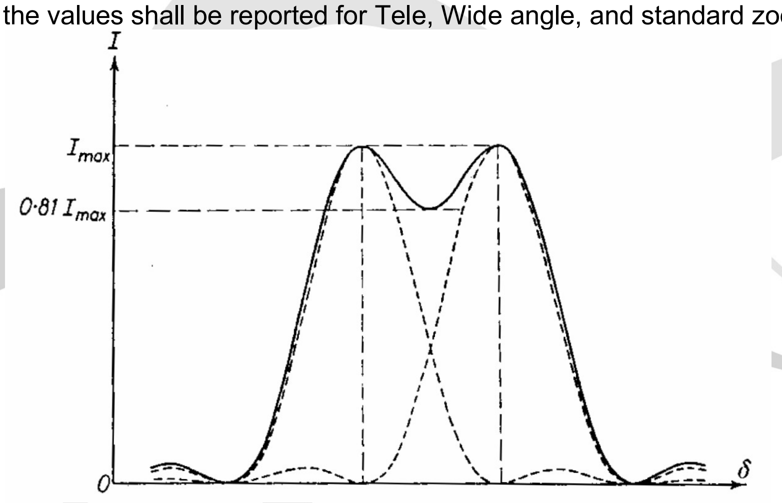
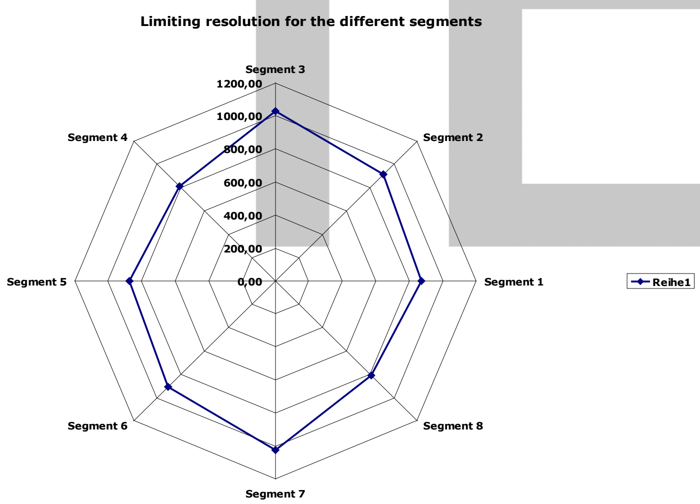


Illustration of two lines just resolved according to the Rayleigh criterion

$$\text{modulation} = \frac{1.0 - 0.81}{1.0 + 0.81} = 0.10$$

11.Figure: According to Lord Rayleigh a modulation of 10% is the limit for the visual perception of fine detail.



12.Figure: spider diagram of the limiting resolution for the segments of a single star.

5.2 Orientation specific image processing

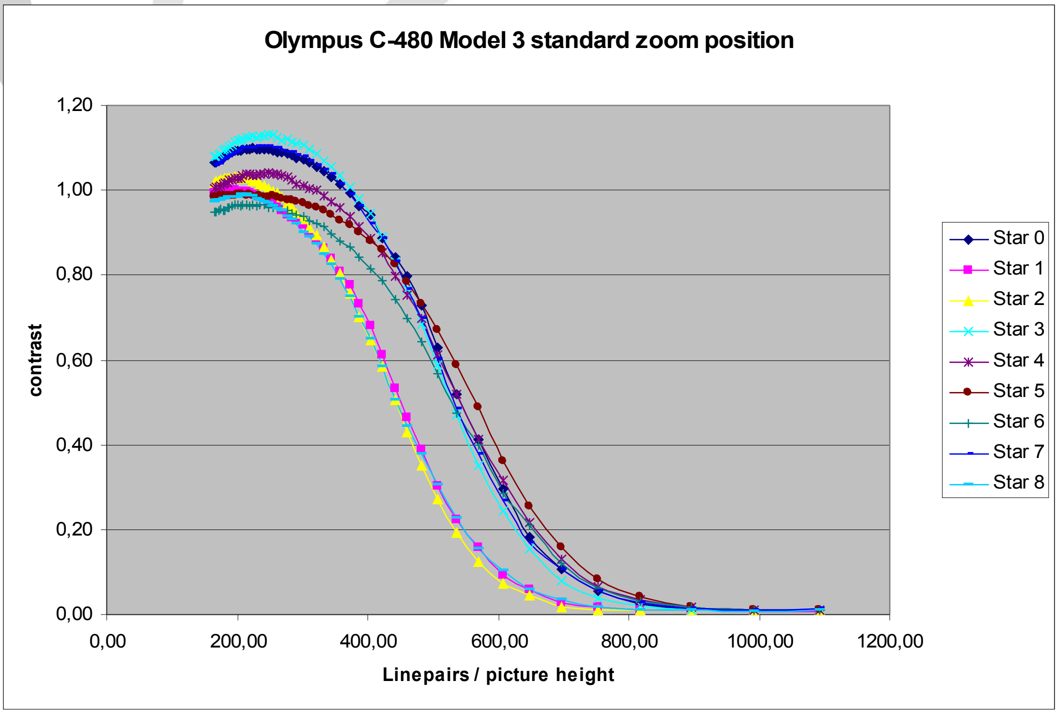
(Software used: IE Resolution + Excel Spreadsheet)
To derive the information for orientation specific image processing it is sufficient to have a closer look at the MTFs for the segments of the central star. Is the contrast at lower frequencies significantly different from one segment to another the image processing is orientation specific.
The spider diagram for the limiting resolution can also indicate this image processing.

5.3 Sharpness

(Software used: IE Resolution + Excel Spreadsheet)
The sharpness of an image is represented by the contrast at low frequencies. Therefore the contrast shall be determined from the MTF as a single value averaged from the contrast at the frequency of 200 Lp/Ph and 400 Lp/Ph (line pairs per picture height). In order to indicate the loss of sharpness from the center to the corners, the value shall be reported separately for the center star and as an averaged value of the corners. For a zoom lens, the averaged values over Tele, Wide angle, and standard zoom position, shall be reported.

5.4 Centering problem

(Software used: IE Resolution + Excel Spreadsheet)
A problem in optical centering can be visualised by looking at the MTFs for the four corner stars. If these stars show a significant variation in sharpness and limiting resolution it is obvious that an optical centering problem exists. To verify the problem the other stars (1,3,5,7) may also be taken into account.



13.Figure: The low contrast of star 1, 2, and 8 indicates a centering problem.

5.5 Astigmatism

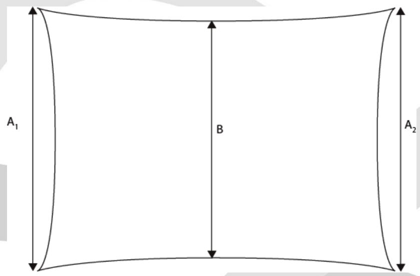
(Software used: IE Resolution + Excel Spreadsheet)
Looking at the stars in the corners. If the limiting resolution of the segments on the imagined line between the corner star and the central star is higher than that of the segments perpendicular to these and if this is the case for all 4 corner stars the lens shows astimatism.

6 OTHER LENS RELATED VALUES

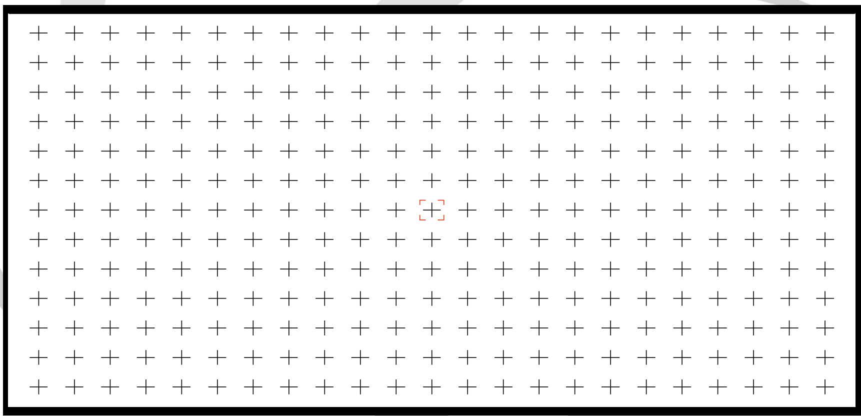
6.1 Distortion

(Software used: IE Analyzer + Excel Spreadsheet)
The distortion shall be measured as SMIA TV distortion in wide angle position as the bending of a horizontal line on the top and bottom of the image in relation to the image height as specified in the SMIA [13] specification, §5.20

$$\text{SMIA TV Distortion} = 100(A-B)/B; \qquad A = (A_1+A_2)/2$$

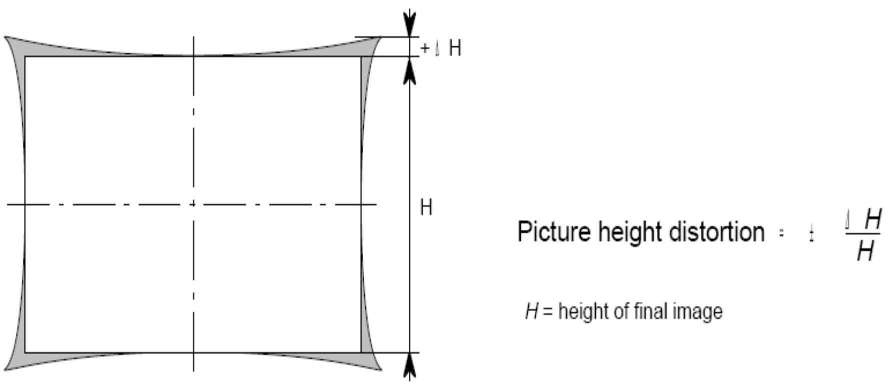


14.Figure: The SMIA TV distortion.



15.Figure: The chart used to measure the distortion an the lateral chromatic aberration consists of crosses distributed over the complete image. The center of the crosses is located with sub pixel precision for all three channels. Frome the locations the distortion and the chromatic aberration can be calculated.

Another distortion measurement often used is the one named TV distortion (described by the EBU in [16]).



16.Figure: The TV Distortion meaurement as described in the EBU specification

6.2 Shading / Vignetting

(Software used: IE Analyzer + Excel Spreadsheet)
An image of a uniform illuminated diffuser plate shall be taken at wide angle position, with open aperture, with the camera close to the plate, and the focus set to infinity. If manual focusing is not available, the diffuser plate shall be photographed with auto focus. The uniformity of the plate has to be greater than 95% and the size shall be at least twice the size of the diameter of the lens.

The exposure shall be adjusted to a maximum digital value between 150 and 200. None of the digital values shall be close to 255 in an 8 Bit image. To avoid the influence of noise the digital values used for the calculation below shall be averaged values of 8 x 8 pixes.

The shading shall be calculated as:

$$S = (D_{max} – D_{min}) / D_{max} *100$$

D_{max} = maximum digital value (averaged over 8 x 8 pixels) in the test image
D_{min} = minimum digital value (averaged over 8 x 8 pixels) in the test image

In order to report the results in f-stops, it is necessary to calculate the f-stops by using the OECF.

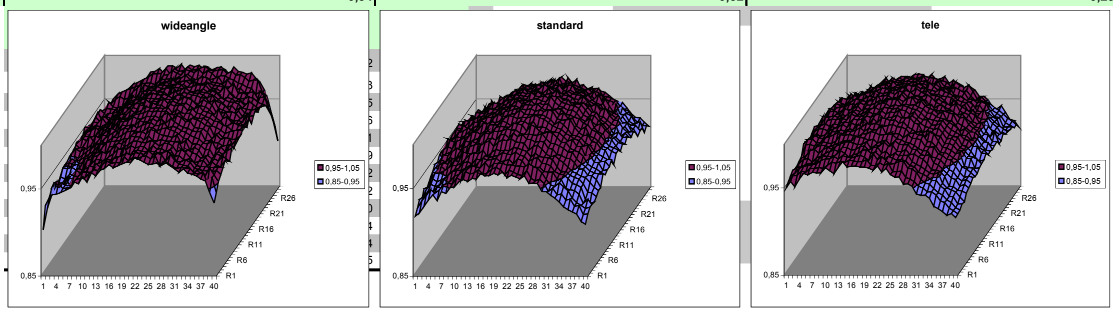
$$S_{f\text{-}stops} = (LL_{Dmax} – LL_{Dmin}) / 0.3010$$

LL_{Dmax} =corresponding log luminance values to $_{Dmax}$ determined from the measured OECF
LL_{Dmin} =corresponding log luminance values to $_{Dmin}$ determined from the measured OECF

If an output oriented value is required, it shall be calculated based on the gamma of sRGB.

measuring shading from the center to the corner

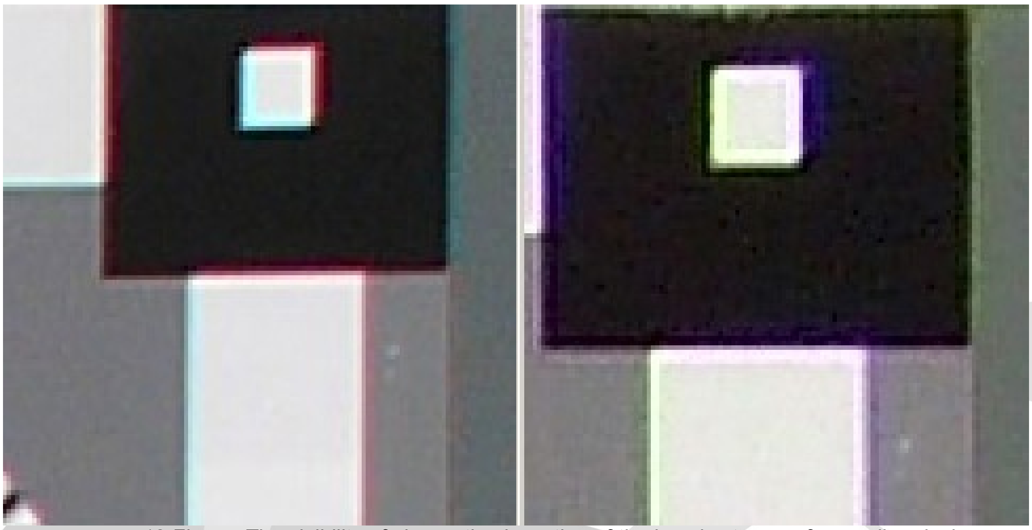
shading	wideangle				standard				tele			
minimum				173,3				175,6				178,7
maximum				192,2				193,1				195,1
average				187,1				186,5				189,4
difference [%]	10%				9%				8%			
	Indizes	Digitalwerte	LOG Lum	LOG Lum	Indizes	Digitalwerte	LOG Lum	LOG Lum	Indizes	Digitalwerte	LOG Lum	LOG Lum
line min	7	153,3	2,38	2,49	7	153,3	2,38	2,50	7	153,3	2,38	2,52
line min	8	181,7	2,54		8	181,7	2,54		8	181,7	2,54	
line max	8	181,7	2,54	2,59	8	181,7	2,54	2,60	8	181,7	2,54	2,61
line max	9	209,0	2,68		9	209,0	2,68		9	209,0	2,68	
Difference [f-stops]				0,34				0,32				0,29



17.Figure: The shading depending on the zoom position given in % and f-stops.

6.3 Chromatic aberration (lateral)

(Software used: IE Analyzer + Excel Spreadsheet)
Small pixel sizes on a sensor also support the visibility of color fringes in the image corners caused by chromatic aberration of the lenses. The chromatic aberration shall be measured locating the center point of a cross (e.g. from the distortion image; Chapter 6.1) in the image corner and report the chromatic aberration as the maximum distance in pixel between the blue and green, and the red and green channel.



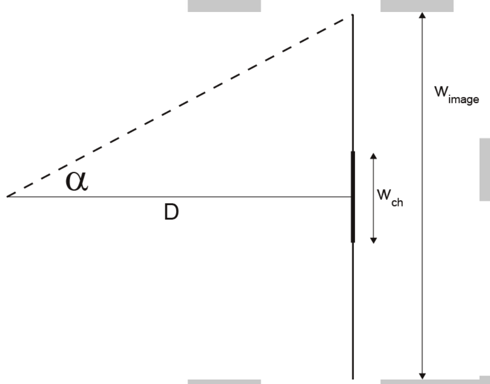
18.Figure: The visibility of chromatic aberration of the lens is stronger for smaller pixels.

6.4 View angle, Zoom range (at infinity and shorter distances)

(No special Software required, Photoshop)

The view angle shall be measured using a test chart with a specific width (min. 1 m) and by taking an image of this chart from a defined distance. The view angle can be calculated from the width of the test chart in relation to the complete image width.

The recommended procedure to calculate a Zoom range or factor is to adjust the distance in a way that at tele position the chart width covers the complete image width. This distance is kept to shoot the wide angle as well and the view angle shall be calculated using the formula below.



$$W_{image} = w_{chart}\ (\text{Image width [pixel] / chart width [pixel]})$$

$$2\alpha = 2\arctan\left(\left(w_{chart}\ (\text{Image width [pixel] / chart width [pixel]}) / D\right)/2\right)$$

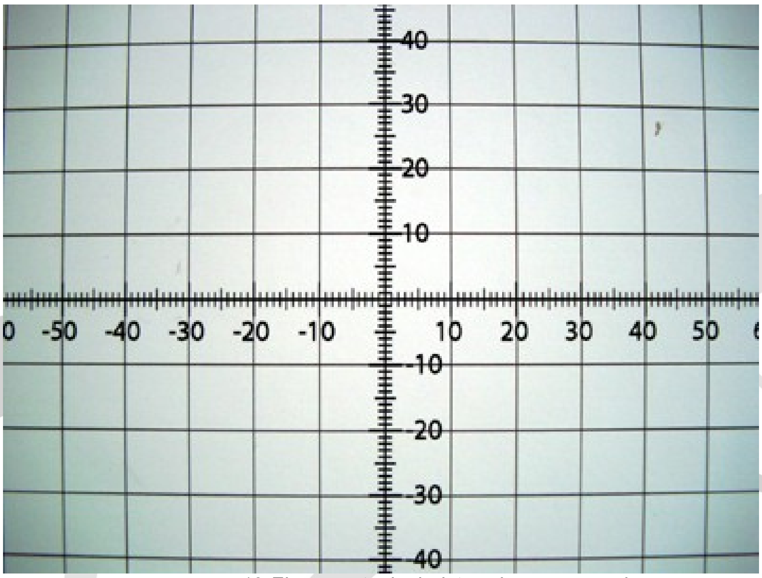
W_{image} = Image width in meter
W_{chart} = Chart width in meter

For D >> focal length the zoom factor F is:

$$F = \frac{W_{image-wide\,angle}}{W_{image-tele}}$$

6.5 Detailed macro mode testing

A lot of cameras allow taking images in a macro mode. But how small is the smallest area that fits a complete image? This value is of importance for medical, mineralogical, or other scientific applications. An image of a scale is taken in macro mode at the shortest distance for a sharp picture.



19.Figure: a typical picture in macro mode

If required the distortion may also be measured in macro mode as described in chapter 6.1.

6.6 Optical stabilization

Some cameras and lenses have an integrated optical stabilization which compensates for hand shaking of the photographer. To test these stabilization methods based on Gyro sensors in combination with a moveable lens or a moveable sensor we need to know the typical frequency and amplitude of a shaking hand.

A test facility is under onstruction and will be part of a diploma thesis at the University of applied science Cologne.

6.7 Auto focus accuracy and constancy

To test the auto focus accuracy and constancy a high contrast object is mounted on an inclined plane. The camera mounted on a tripod in a typical shooting distance of about 2.5 meters focuses on this object and takes pictures. These pictures are visually analyzed. The sharpest plane always has to be on the object. If it is located in front or behind the object the camera or lens has a focus problem.

To test the constancy a set of at least 10 images shall be taken. After each image the camera shall focus on an object in a different focal distance and then refocus on the high contrast object.

20.Figure: In the image on the right the object is in focus. On the left side the focal plane is far behind the object.

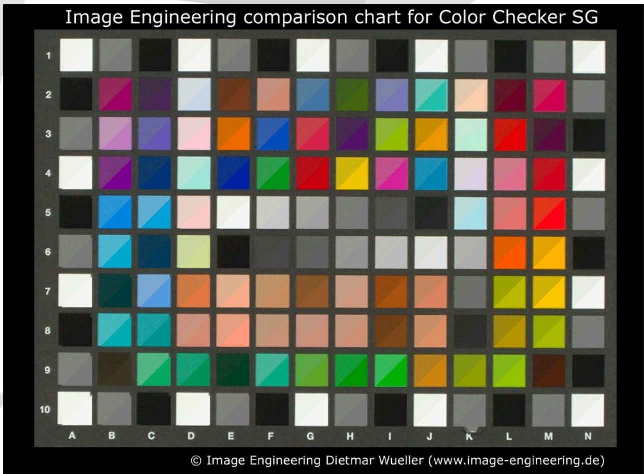
7 COLOR

7.1 Color reproduction

(Software used: IE Analyzer + Excel Spreadsheet)

To achieve a nice looking image is one thing, the exact reproduction of the original scene another. The nice looking image can only be determined by a statistic analysis of the opinions of a large number of people reviewing images. The color reproduction quality can be measured. In order to do this an image of the Gretag Macbeth Color Checker SG is taken (for mobile phone cameras in the current stage, it may be necessary to use the standard Color Checker instead of the SG because of the low number of pixels). The colors of the chart are known or measured as XYZ and Lab values measured with a spectral photometer. If the manufacturer does not report anything else, we assume that the images taken with the camera are provided in the sRGB color space as defined in IEC 61966-2-1, because this is the color space specified in Exif 2.1 as output space for digital cameras using the Exif file format. The taken images are transferred to Lab representing the color reception of the human visual system and the color distance ΔE (as specified in DIN 6174), as well as the components ΔL, ΔC, and ΔH, can be measured. The average ΔE value shall be reported as color reproduction quality.

The lower the ΔE values are, the better the color reproduction of the original scene.



21.Figure: To visualize the color differences a file can be used which has the values of the original chart in the lower right corners and the value of the test image in the upper left. The Photoshop sample file can be downloaded from 14.

Delta L														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	2,12	6,77	5,54	3,08	8,27	4,73	3,69	9,55	4,43	3,69	9,74	3,76	9,45	3,18
2	4,85	6,23	5,00	9,51	2,82	11,70	9,45	7,43	9,36	17,91	8,69	1,46	6,82	8,55
3	6,05	8,47	3,74	7,91	7,81	6,30	6,90	1,46	14,16	11,39	7,59	4,82	1,79	3,65
4	1,46	6,63	2,88	8,68	2,55	16,98	8,63	10,08	7,64	12,80	8,75	7,95	5,96	1,84
5	5,47	9,19	13,68	6,20	2,17	9,13	10,18	6,78	1,98	5,55	8,03	6,33	0,91	4,89
6	3,09	13,64	3,71	6,91	5,02	1,51	2,41	8,24	8,45	4,82	8,08	2,29	3,77	5,48
7	0,77	4,85	7,37	4,20	5,20	7,30	2,85	7,28	2,85	4,81	2,11	7,68	4,76	0,87
8	5,84	12,19	9,37	4,69	3,60	5,56	6,02	5,87	0,97	4,35	7,74	5,08	6,41	1,02
9	0,36	9,89	9,73	10,57	6,20	12,85	7,39	12,01	12,84	3,23	5,82	6,17	7,35	5,61
10	2,72	0,43	6,18	1,57	1,07	5,88	1,17	1,45	6,04	1,40	0,77	5,70	0,06	2,81
average Delta L		6,00												

Delta c														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	0,25	0,27	0,07	0,25	0,47	0,08	0,24	0,54	0,03	0,24	0,68	0,15	0,70	0,19
2	0,15	9,96	10,74	5,52	18,00	0,27	10,80	9,41	10,24	8,38	9,67	11,21	10,86	0,77
3	0,43	6,71	21,12	6,80	0,05	29,60	14,49	9,02	0,09	0,36	9,97	10,72	1,90	0,34
4	0,20	11,58	12,04	3,50	10,33	10,75	14,17	8,96	12,79	0,12	5,31	6,06	13,45	0,23
5	0,11	10,50	6,32	6,50	0,24	0,17	1,20	1,45	1,79	0,90	6,01	4,94	6,19	1,43
6	0,59	4,34	1,55	5,48	0,20	0,90	1,88	1,98	1,27	0,95	1,36	8,41	9,29	0,07
7	0,24	14,76	2,93	8,98	3,79	5,75	15,24	2,58	17,81	6,80	2,49	9,94	11,97	0,14
8	0,05	1,45	13,68	4,26	2,66	5,19	5,13	4,41	15,71	4,92	1,49	8,35	4,31	1,02
9	0,61	0,63	5,87	4,57	8,13	4,05	12,47	10,80	5,76	9,80	9,03	1,86	1,07	0,12
10	0,06	0,56	0,20	0,30	1,45	0,07	0,39	1,64	0,26	0,46	2,21	0,26	1,88	0,59
average Delta c		4,92												

Delta h														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	148,47	52,72	134,13	72,92	31,78	177,90	57,46	31,02	179,19	47,62	21,27	139,34	27,48	29,24
2	122,86	12,45	5,19	14,00	0,42	8,41	4,50	0,32	4,31	3,13	12,31	11,95	7,02	17,35
3	19,64	4,58	1,62	4,90	3,15	4,65	5,25	3,54	0,30	6,90	12,99	5,39	11,45	150,31
4	55,49	4,27	19,02	3,82	7,60	4,67	8,67	6,05	4,28	21,63	20,66	2,67	10,02	73,97
5	167,81	13,77	5,80	0,85	131,27	32,66	48,82	55,81	60,06	172,97	8,53	1,97	5,50	42,59
6	53,20	5,17	40,54	0,52	177,25	86,94	82,90	46,72	42,62	56,19	56,48	1,26	10,56	167,73
7	80,50	22,39	0,43	5,41	5,93	1,37	5,39	4,39	1,75	5,20	23,14	4,03	5,08	48,52
8	178,52	7,95	12,14	4,85	6,74	0,89	1,87	3,17	0,95	3,29	124,57	0,43	2,24	57,02
9	52,17	2,38	4,82	4,18	6,65	3,13	3,01	0,89	3,72	1,44	2,53	0,72	7,43	167,33
10	21,43	67,61	135,40	39,86	44,85	161,16	17,57	42,29	175,01	60,39	45,96	177,38	41,38	91,94
average Delta h ohne		17,73												
average Delta h		38,78												

Delta E														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	2,15	6,79	5,61	3,09	8,30	4,91	3,70	9,57	4,63	3,70	9,77	3,86	9,48	3,18
2	4,92	17,51	12,18	11,09	18,23	12,45	14,56	12,00	14,12	19,88	13,40	14,34	15,49	8,59
3	6,07	11,20	21,50	10,48	9,07	30,76	17,14	9,58	14,16	15,19	12,76	14,58	7,11	3,76
4	1,48	14,35	19,04	9,43	14,23	20,78	21,07	16,30	15,69	21,53	10,46	10,19	20,79	1,86
5	5,58	19,67	15,63	8,98	2,19	9,16	10,32	7,00	2,88	5,88	10,22	8,18	10,64	5,14
6	3,22	14,85	20,01	8,82	5,18	2,47	3,54	8,59	8,64	4,96	8,35	8,95	19,18	5,70
7	0,81	17,20	7,94	11,14	7,13	9,33	15,96	7,95	18,12	9,12	3,29	13,98	15,23	0,88
8	5,98	13,68	19,02	6,87	6,32	7,62	7,96	7,50	15,76	6,94	8,11	9,79	8,33	1,71
9	1,00	9,92	12,05	12,16	10,51	13,72	14,81	16,19	14,88	10,43	11,09	6,52	8,02	5,80
10	2,72	1,16	6,30	1,60	1,98	6,09	1,23	2,34	6,15	1,49	2,52	5,85	2,03	2,87

average Delta E	9,622

22.Figure: Table of the Delta L, C, h and E values

7.2 Color resolution

The ISO technical committee 42 (photography) working group 18 (digital photography) discusses the introduction of a method to measure the resolution for colors separately. Due to the Bayer pattern on most of the current sensors the resolution may be different for the different colors. Since a specific procedure has not yet been figured out we will observe the development and this measurement as soon as it is developed.

8 SENSOR RELATED VALUES

8.1 Hot pixels

(No special Software required, Photoshop)
Pixels with unusual behavior are pixels or pixel clusters which show a digital value significantly above the typical noise level (usually >20) for an image taken in complete darkness at a specified exposure time (if possible). Further investigation is necessary.

8.2 Spectral sensitivities

(Only available as a service, no devices or software available)
We are able to measure the spectral sensitivities of a camera as long as we have access to the raw data and are able to convert these into tiff or Adobe DNG format. These measurements are useful to increase the quality of the raw converting software.

8.3 Bit depth of raw data

(Software used: IE Analyzer + Excel Spreadsheet)
Analysing the histogram of a high contrast raw image shows the bit depth the camera is able to deliver.

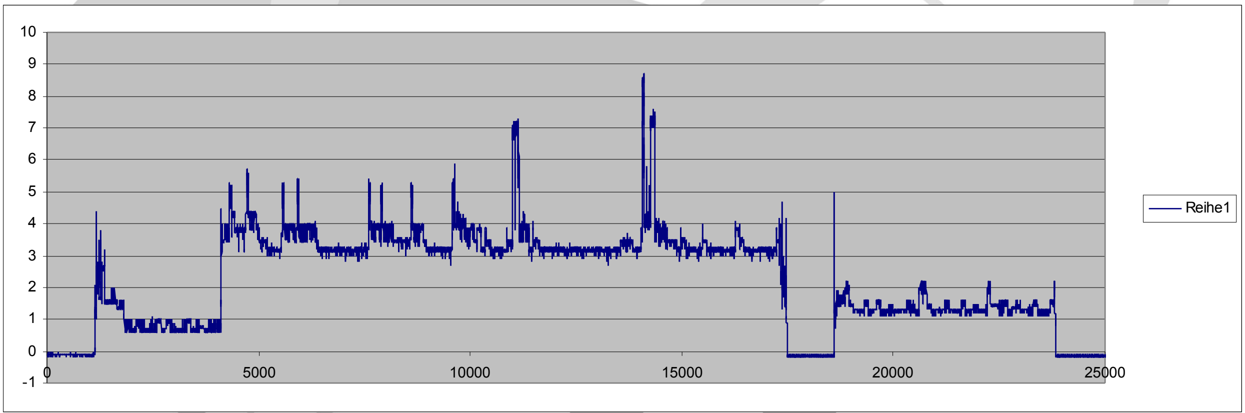
9 POWER

9.1 Power consumption

The timeline of the power consumption using a stabilized power supply and a special PC-I/O-Card is measured. 100 values per second show the differences in detail and lead to a precise description of the cameras behavior according to power consumption. The timescale shows different operating modes and can be used to characterize different time values and speeds of interest.

9.2 Power consumption over a test cycle

To compare the power consumption of different cameras it is necessary to define a fixed test cycle and to integrate the consumption over the whole cycle. This cycle should represent a typical use of a digital camera. It is first switched on and the auto focus is activated to focus on an object far away. Afterwards the camera is pointed on an object near by (50 cm) and the button is pressed to take one picture without and another with flash. The camera is switched off and on again in play mode. A number of different images are displayed for a defined time and the camera is switched off again.



23.Figure: A sample test cycle for the power consumption measurement.

9.3 Battery life

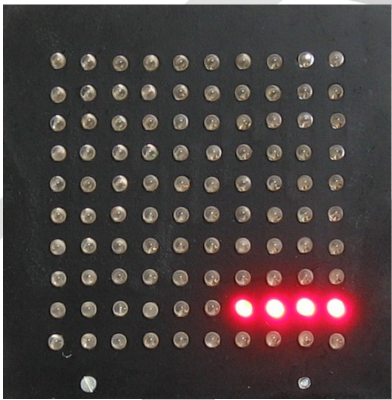
The battery life is tested using the CIPA standard which can be downloaded from

http://www.cipa.jp/english/hyoujunka/kikaku/pdf/DC-002_e.pdf

10 TIMING

10.1 Shutter lag

(No Software required)
Everybody who ever took a picture with a consumer digital camera knows the effect. Nothing happens after pressing the button and then after a few seconds, an image is exposed and another photo of somebody's legs has been taken.
Part of the time in between is needed to focus and part is needed to adjust the exposure. The overall time from pressing the button until the image is exposed is called shutter delay or shutter lag. In the past shutter lag could be measured using the timescale of the power consumption. Nowadays the peaks in power consumption when pressing the exposure button are often not visible. Therefore, we had to find another way to determine shutter lag. We came up with a method using a panel with 100 LEDs which are "running" in a selectable frequency. This means that every LED is illuminated for a defined period of time until the next one lights up. The LEDs start running after a micro switch fixed on the exposure button is pressed. The first LED lit on the image taken by the camera defines shutter lag.
In order to include the focus time, the camera shall focus on an object close to infinity and then be turned to face the LED panel at a 1.5m distance. This ensures a defined focus situation and the reproducibility. In order to exclude the autofocus, it shall either be switched off or the camera shall focus on the LED panel first before the image is taken. Both values shall be reported.



24.Figure: An LED panel is used to measure shutter lag.

10.2 Startup time

(No Software required)
A snapshot situation occurs which needs to be captured. If the camera needs a long time to get ready, the situation will be gone. Therefore, the time needed to get ready to shoot after turning on the camera is an important value which can be determined using a simple stop watch.

For mobile phone cameras the startup time shall be determined using the fastest way to activate the camera from the standby mode.

10.3 Image frequency

(No special Software required, Photoshop)
Image frequency is determined by how fast after taking one image the camera is ready to shoot the next one. We call this the continuous shooting frequency. It is measured using the LED panel again in JPEG highest quality / lowest compression mode.
When the camera is ready to take a picture, the release button of the camera is pressed together with the microswitch of the LED panel. Another picture shall be taken as fast as possible and this shall be repeated

until the internal memory of the camera is full so that the frequency slows down or a set of at least 10 images is taken. The images devided by the time required to take them is the image frequency. If the internal memory is the limitation for the number of images the number until the camera slowed down shall be reported.

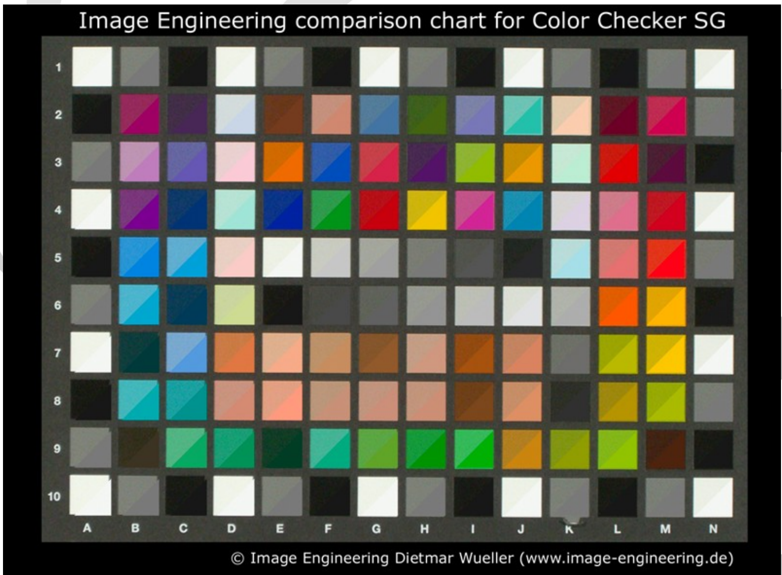
$$F = \frac{N}{t}$$

F = frequency [frames / second]
N = Number of images
t = time required to take the images

10.4 Exposure and Exposure time accuracy and constancy

(No Software required, Photoshop)
A low contrast scene (between 60:1 and up to 100:1) shall be set up with an overall reflectance of 18%.
The 18% reflection area shall reach a digital value between 100 and 130 (for gamma 2.2 the target value is 117) which shall be constant over a sequence of at least 10 images. No highlights shall be clipped.

An image of the Color Checker SG fulfills this requirement and the patch H5 shall be used as 18% reflectance reference.



25.Figure: The Color Checker SG has a contrast of about 91:1 and an average reflectance of 18%.

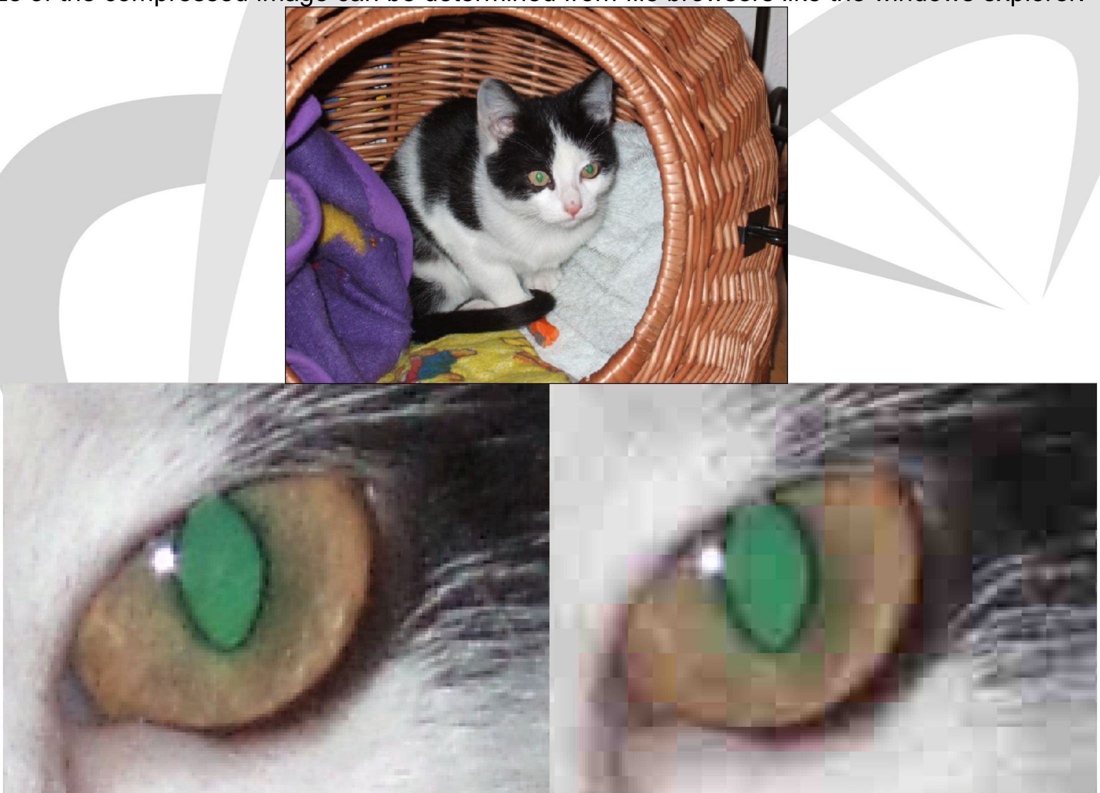
11 IMAGE PROCESSING

11.1 Compression rates

(No special Software required, Photoshop and Explorer)
Since all camera phones use JPEG compression to reduce the file sizes of the images, and the compression is a lousy one, it is interesting to know the compression rates of an image with fine details (e.g. resolution chart). These compression rates shall be given in percent of the size for the uncompressed image with a color depth of 8 Bit (1 Byte) per channel. Usually the size of the uncompressed color image can be calculated from the pixel count:

Image size [Byte] = Number of pixels x 3

The size of the compressed image can be determined from file browsers like the windows explorer.



26.Figure: The detail of the picture above shows the cat's eye in a low compresion on the left and a high compression on the right side. The related file sizes are 17.4 MB uncompressed, 3.66 MB with a low compression, 200kB with high compression.

The compression rates are calculated as:

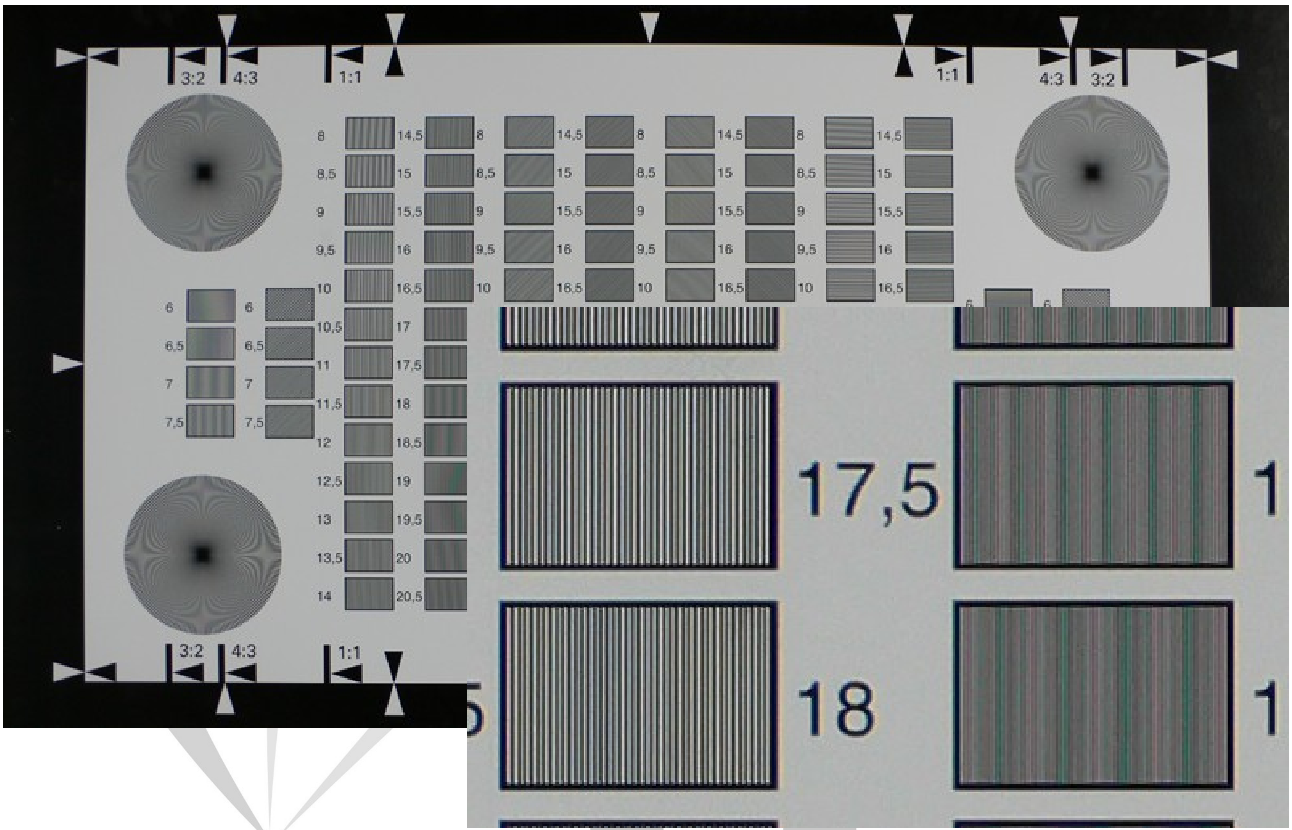
$$C = \frac{I_C}{I_U} \cdot 100$$

with
C = Compression rate
I_C = size of the compressed image
I_U size of the uncompressed image

for our sample:	low compression	C= (3.66/7.4)100 = 21%
	high compression	C= (0.2/7.4)100 = 1.1%

11.2 Aliasing

Although some aspects like a modulation beyond the Nyquist frequency indicate the existance of aliasing in an image there is no measure for alisaing so far. The only approach is a visual one using images of high frequency structures which might cause these artifacts.



27.Figure: specific test charts can be used to visualize the aliasing behaviour of the camera.

11.3 Metadata (Exif, IPTC)

The ability of a camera to store Metadata can be checked using an image processing software which is able to read the different kinds of standardized data. One example is Adobe Photoshop.

11.4 Watermarking

A German standardisation project wants to standardise the implementation of robust and fragile watermarks in digital cameras. So far there is no such standard and the test we have performed were limited to the Canon Image Verification Software.

As soon as the watermarking will become widespread we will come up with a procedure to test these protection algorithms.

12 FLASH CAPABILITIES (UNIFORMITY, GUIDING NUMBER LIGHT SOURCE, ETC.)

12.1 Light source

Some camera phones use an LED instead of a flash as additional light source for dark scenes. Therefore the kind of light source shall be reported.

12.2 EV/guiding number

At a distance of 1m to the phone, the light is measured using an exposure meter. In the case of an LED or another continuous light source, the exposure value is measured. In the case of a flash as the light source, the guiding number is measured and transferred into an exposure value using 1/60 of a second as sync time for the calculation.

At ISO 100 the guidng number is defined as:

$$Z = r \cdot k$$

with
r = distance in meter
k = f-stop

The exposure value can be calculated using:

$$EV = \frac{2 \cdot \log k - \log t}{\log 2}$$

with
t = exposure time
k = f-stop

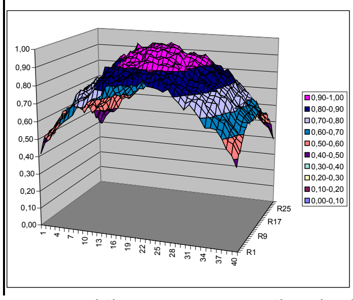
12.3 Uniformity

(Software used: IE Analyzer + Excel Spreadsheet)
How uniform the flash or LED illuminates the exposed scene is another criterion for the quality of images taken with the additional light source. An image of a neutral grey wall shall be taken from a distance of 2m. The measurement uses the same analysis as described in shading/vignetting.

uniformity

digital values		Log Luminance	red	green	blue	y
minimum	33	-1,00	0	0	0	0
maximum	86	0,05	0	0	0	0
average	66	0,57	1	1	1	1
difference [%]	-61%	1,36	30	29	26	29
		1,84	83	80	80	81
		2,09	117	117	117	117
		2,31	158	156	158	157
		2,47	184	183	186	184
		2,62	210	210	212	210
		2,77	235	235	236	235
		2,88	250	250	250	250
		2,99	255	255	255	255

Row	Log Luminance	y	Log Luminance
4	1,36	29	1,40
5	1,84	81	
5	1,84	81	1,88
6	2,09	117	
Differencein f-stops			1,59



28.Figure: The uniformity is measured the same way as the shading/vignetting in % or f-stops.

13 VIDEO CAPABILITIES (PIXEL COUNT, RESOLUTION, FRAME RATE, LOW LIGHT BEHAVIOR)

13.1 Pixel count

(No special Software required, Premiere or an equivalent software)
The number of pixels [horizontal x vertical] in the video stream

13.2 Frames per second good lighting conditions

(No special Software required, Premiere or an equivalent software)
The number of frames per second captured in video mode. After a conversion into typical video codecs such as AVI, numerous video editing programs are able to analyze the frequency of the captured stream.
Good lighting conditions in this case mean an illumination with more than 1000 lx in the scene.

13.3 Frames per second bad lighting conditions

(No special Software required, Premiere or an equivalent software)
The number of frames per second captured in video mode. After a conversion into typical video codecs such as AVI, numerous video editing programs are able to analyze the frequency of the captured stream.
Bad lighting conditions in this case mean an illumination with 50 lx in the scene.

14 MMS CAPABILITIES FOR MOBILE PHONE CAMERAS (RESOLUTION, FRAME RATE, COMPRESSION ETC.)

(No special Software required, Photoshop, Explorer)
Resampling for MMS (yes/no; pixel count; file size/compression)
Due to limiting bandwidth, some of the mobile phone cameras resample the images to lower pixel counts and higher compressions. So the pixel count, as well as the file size, indicates the loss of quality in this case.

The pixel count shall be reported and the compression shall be calculated using the algorithm described in chapter 11.1.

15 DISPLAY (REFRESH RATES, GEOMETRIC ACCURACY, COLOR ACCURACY)

15.1 Refresh rate

(No special Software required)
The refresh rate of displays can be tested by using a frequency generator together with a LED. The frequency can be varied in the typical expected refresh rate. If the LED is constantly illuminated on the display of the camera phone, the LED and the refresh rate have the same frequency which can be determined from the display of the frequency generator.

15.2 Display accuracy

(No special Software required)
The display accuracy is a statement whether the display and the captured image are identical. It is possible that the display shows only a part in the center, or in another region of the captured image. The macro chart or the distortion chart shall be captured in a way that the chart fills the complete displayed image. The resulting image shall then be compared with the original.

15.3 Color accuracy

(set of image files and software for the spectral photometer and profiling software)
The only way to measure color accuracy of the display is to use a spectral photometer and measure a displayed sRGB image with defined colors on the display. An average delta E value as described in chapter 7.1 can be calculated. Using the RGB patches displayed by a profiling software like Gretag Macbeth Color Checker a profile for the display can be calculated which represents the color gamut of the display.

The method is time consuming and in combination with the impact of the surrounding illumination, it does not seem to be that useful.

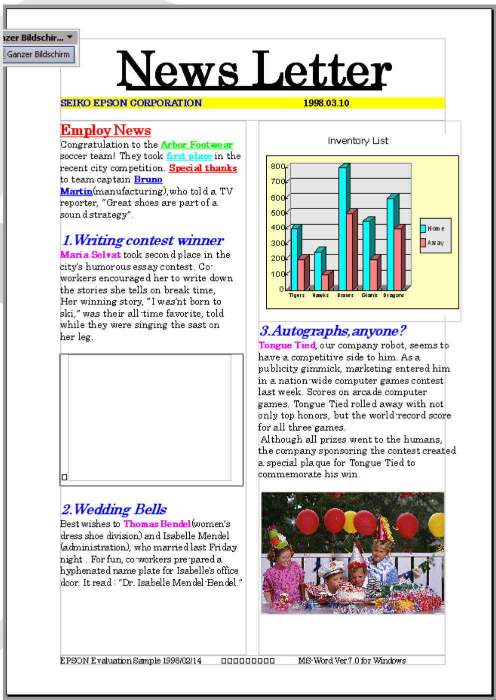
15.4 Visibility under bright light conditions

To be done.

16 VISUAL DETERMINATION OF A LETTER AND A TEST SCENE

16.1 Readability of a letter

An A4 or letter-sized page of a newspaper shall be captured with autofocus and automatic exposure to check if the text is readable.



News Letter

SEIKO EPSON CORPORATION 1998.03.10

Employ News

Congratulation to the **Arbor Footwear** soccer team! They took **first place** in the recent city competition. **Special thanks** to team captain **Bruno Martin**(manufacturing),who told a TV reporter, "Great shoes are part of a sound strategy".

1.Writing contest winner

Maria Selvat took second place in the city's humorous essay contest. Co-workers encouraged her to write down the stories she tells on break time, Her winning story, "I was'nt born to ski," was their all-time favorite, told while they were singing the sast on her leg.

2.Wedding Bells

Best wishes to **Thomas Bendel**(women's dress shoe division) and Isabelle Mendel (administration), who married last Friday night . For fun, co-workers pre-pared a hyphenated name plate for Isabelle's office door. It read : "Dr. Isabelle Mendel-Bendel."

Inventory List

	Tigers	Hawks	Braves	Giants	Dragons
Home					
Away					

3.Autographs,anyone?

Tongue Tied, our company robot, seems to have a competitive side to him. As a publicity gimmick, marketing entered him in a nation-wide computer games contest last week. Scores on arcade computer games. Tongue Tied rolled away with not only top honors, but the world-record score for all three games.

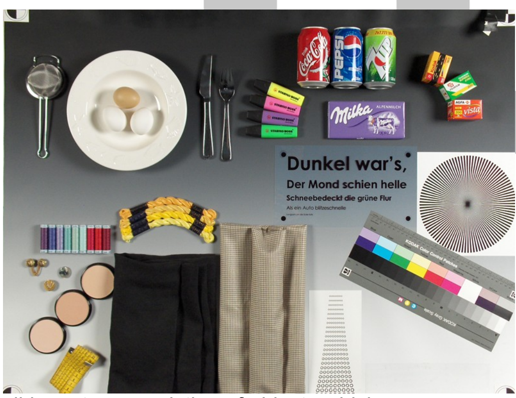
Although all prizes went to the humans, the company sponsoring the contest created a special plaque for Tongue Tied to commemorate his win.

EPSON Evaluation Sample 1998/02/14 MS-Word Ver.7.0 for Windows

29.Figure: Apicture of a sample letter or a part of a Newspaper shall be taken and then be checked for readability.

16.2 Test scene

A test scene shall be photographed which consists of highlights, shadows, spot colors, flash tones, skin tones, and fine details in low and high contrast areas.



30.Figure: A test scene shall be set up consisting of objects which may cause problems for digital cameras.

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