Proposal for a Standard Procedure to Test Mobile Phone Cameras

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ABSTRACT

Manufacturers of mobile phones are seeking a default procedure to test the quality of mobile phone cameras. This paper presents such a default procedure based as far as possible on ISO standards and adding additional useful information based on easy to handle methods. In addition to this paper, which will be a summary of the measured values with a brief description on the methods used to determine these values, a white paper for the complete procedure will be available.

Keywords: digital photography, image quality, noise, dynamic range, resolution, ISO speed, shutter lag, power consumption, SFR

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.

<u>The following aspects are mandatory:</u>

- OECF
- White balancing
- Dynamic range (related scene contrast)
- Used digital values
- Noise, signal to noise ratio
- Resolution (limiting resolution center, corner)
- Sharpness

<u>Recommended values are:</u>

- Distortion
- Shading / vignetting
- Chromatic aberration
- Color reproduction
- Unsharp masking
- Shutter lag / Startup time
- Aliasing artifacts
- Compression rates
- Exposure and exposure time accuracy and constancy
- ISO speed

<u>Optional values may be:</u>

- 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 …)
- 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)

The following values may be tested if available and applicable.

- *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*

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Since this paper can not cover all of the procedures in detail, I would like to refer to our white paper which can be downloaded from http://digitalkamera.image-engineering.de/index.php/Downloads .

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 optimum image quality.

For this proposal the first way is selected because the typical camera phone user is inexperienced in photography. 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 proposed test procedure we chose the settings to maximize the image quality provided by the camera.

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 high 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 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
2. USB
3. Bluetooth

4. Irda
5. MMS

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 phone. 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.

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 test charts the integrating sphere may be replaced by a typical reprographic daylight illumination.
- 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.

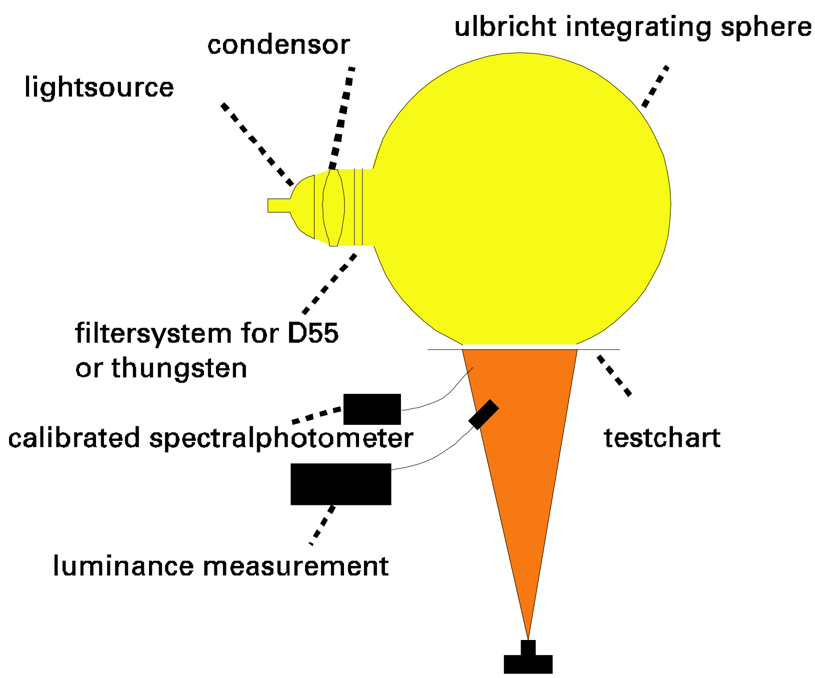


Figure 1: a sample set up for a uniform illuminated transparent test chart.

OECF MEASUREMENTS

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.

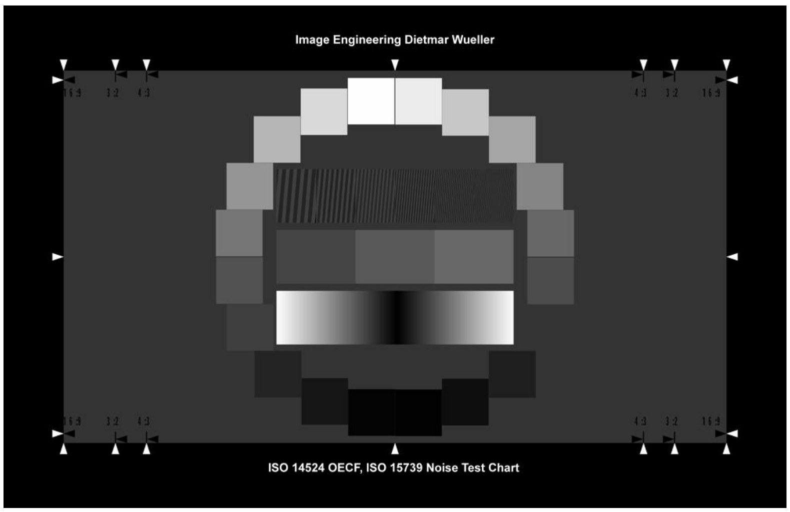


Figure 2: The OECF chart of ISO 14524 combined with the noise patches of ISO 15739. This is a special version with 20 grey levels.

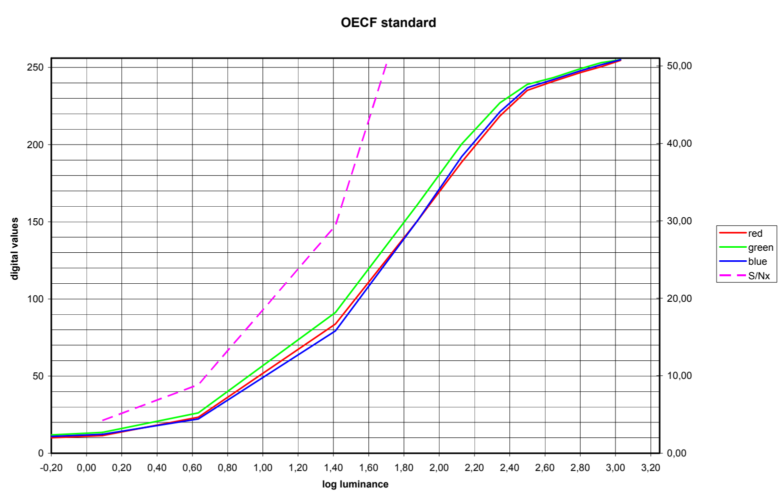


Figure 3: A sample OECF curve for a camera with a high dynamic range.

DYNAMIC RANGE

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.

WHITE BALANCING

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

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.

NOISE AND ISO SPEED

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 2).

RESOLUTION

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.

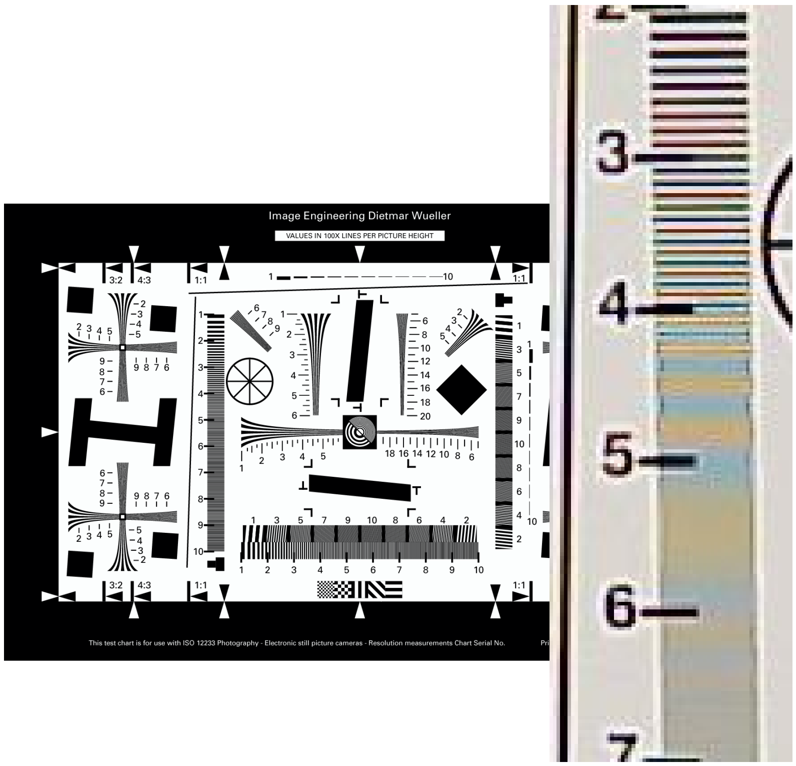


Figure 4: visual analysis of limiting resolution is often not as easy as we expect it to be

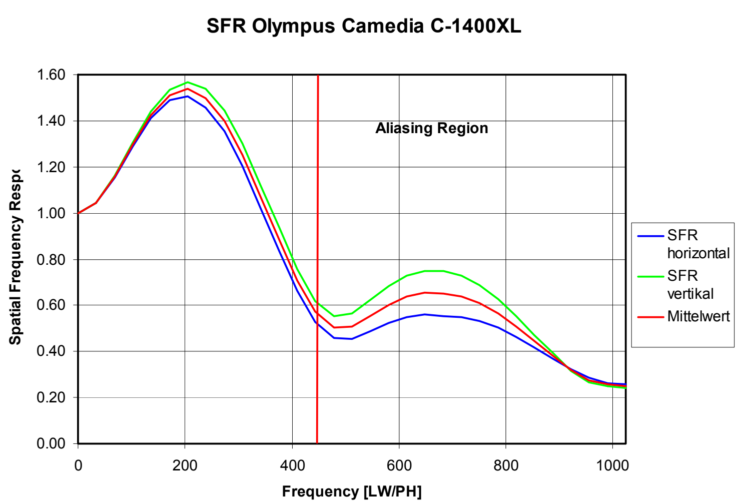


Figure 5: This SFR shows the correct analysis of the slanted edge but it does not represent the MTF of the system.

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 4) and is downloadable from the CIPA website (http://www.cipa.jp/english/hyoujunka/kikaku/cipa_e_kikaku_list.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 white paper downloadable from the Image Engineering website.[4]

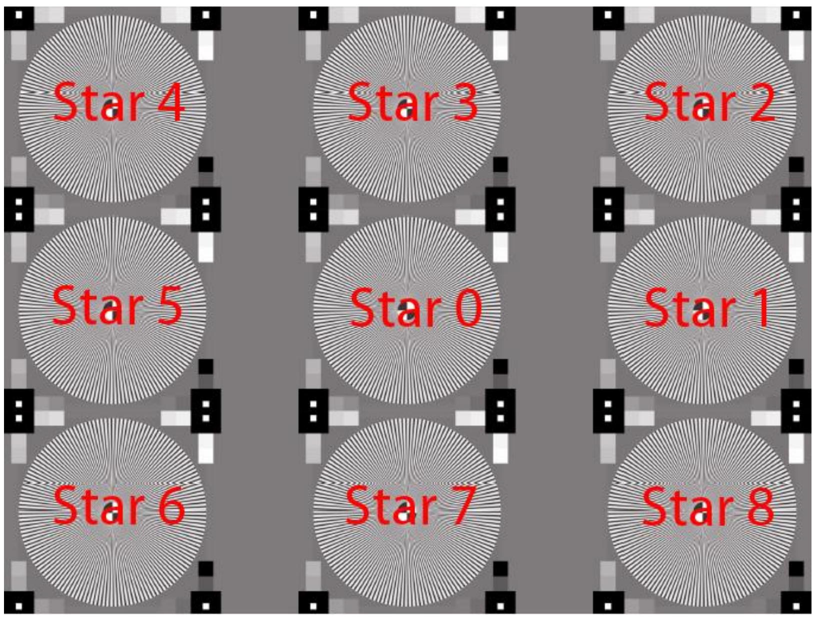


Figure 6: The location of the 9 modulated Siemens stars.

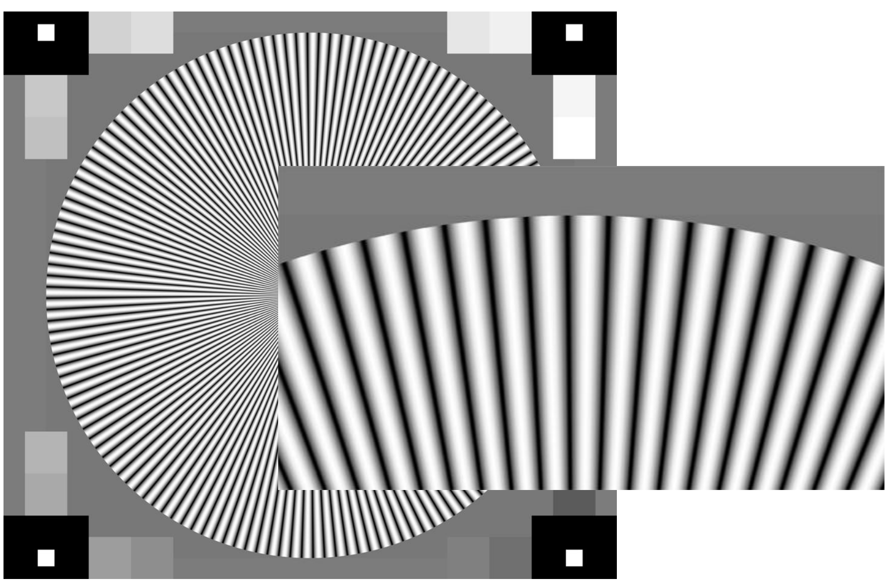


Figure 7: Each star has a modulation which is sine shaped in reflection and surrounding grey patches to linearize the data.

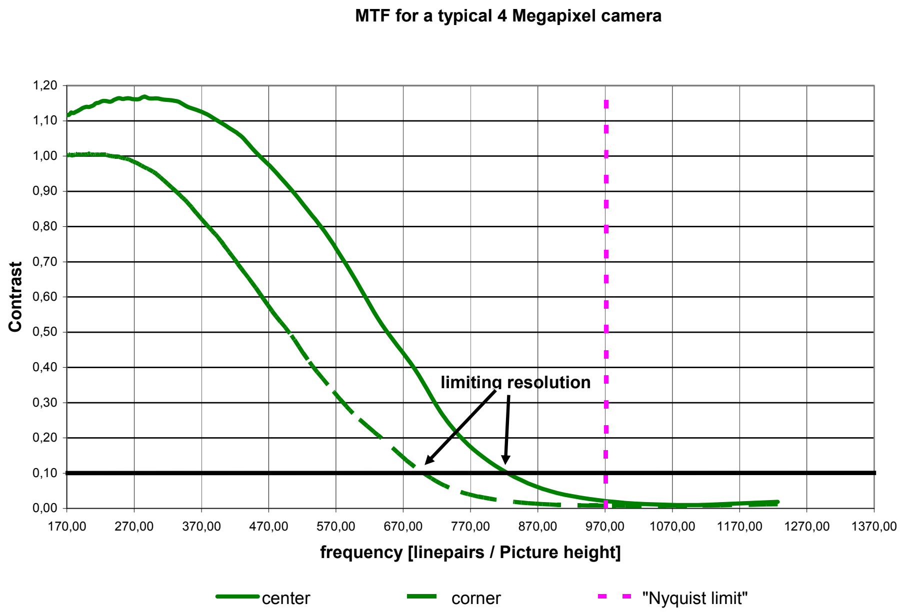


Figure 8: The MTF for a typical camera with the limiting resolution at 10% contrast

The limiting resolution shall be determined as the frequency where the MTF (modulation transfer function) measured with the modulate Siemens Star method passes by the contrast value of 10%. The value shall be reported for the center star and as an average value for the 4 stars in the corner. If only one resolution value is needed, it shall be calculated as an average value from the limiting resolution in the center and the average value for the corners.

SHARPNESS

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.

DISTORTION

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

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

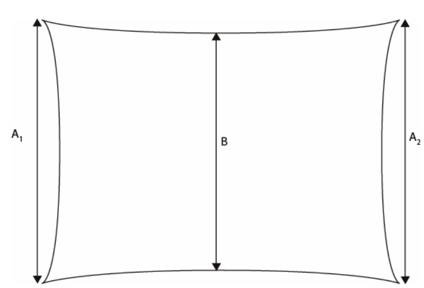


Figure 9: The SMIA TV distortion.

SHADING / VIGNETTING

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. The shading shall be calculated as

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

D_{max} = maximum digital value in the test image
D_{min} = minimum digital value 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.

CHROMATIC ABERRATION

The chromatic aberration shall be measured locating the center point of a cross (e.g. from the distortion image) 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.

COLOR REPRODUCTION

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 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 Δ values are, the better the color reproduction of the original scene.

Figure 10: 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.

SHUTTER LAG

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.

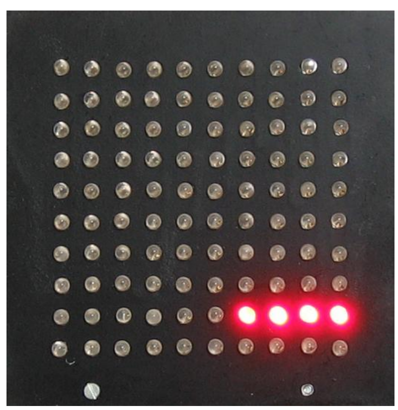


Figure 11: An LED panel is user to measure shutter lag.

STARTUP TIME

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 activating the camera in the phone is an important value which can be determined using a simple stop watch.

COMPRESSION RATES

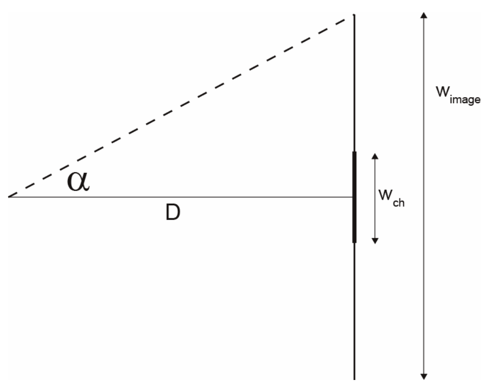
Since all camera phones use JPEG compression to reduce the file sizes of the images, and the compression is a lousy one, it is interesting to know the compression rates of an image with fine details (e.g. resolution chart). These compression rates shall be given in percent of the size for the uncompressed image with a color depth of 8 Bit per channel.

EXPOSURE AND EXPOSURE TIME ACCURACY AND CONSTANCY

A low contrast scene (between 60:1 and up to 100:1) shall be set up with an overall reflectance of 18%. A patch with an 18% reflection shall reach a digital value between 100 and 130 (for gamma 2.2 the target value is 117). No highlights shall be clipped.

VIEW ANGLE, ZOOM RANGE (AT INFINITY AND SHORTER DISTANCES)

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.



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

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

HOT PIXELS

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.

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

Light source
It is necessary to know whether the camera phone uses a flash or an LED as the additional light source for dark scenes.

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.
Uniformity
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.

IMAGE FREQUENCY

[Frames per second]
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 mode.
When the camera phone is ready to take a photo, press release buttons of the camera and the chronometer (or LED panel) in the same time. Then take another picture as fast as possible. The result is in the second picture.

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

Pixel count
The number of pixels [horizontal x vertical] in the video stream
Frames per second good lighting conditions
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.
Frames per second bad lighting conditions
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.

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

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.

DISPLAY (REFRESH RATES, GEOMETRIC ACCURACY, COLOR ACCURACY)

Refresh rate
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.
Display accuracy
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.

Color accuracy
The only way to measure color accuracy of the display is to use a spectral photometer and measure a single color on the display. This is a time consuming method and it includes the characteristics of sensor image processing and display. In combination with the impact of the surrounding illumination, measuring this value does not seem to be worth the effort.

VISUAL DETERMINATION OF A LETTER AND A TEST SCENE

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

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