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# Image Stabilization Performance: Existing standards and the challenges for mobile imaging

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## Abstract

*Cameras in mobile phones are supposed to capture images under a huge variety of lighting conditions while mostly hand held. To improve the performance in low light conditions, image stabilization shall optimize the resulting image by reducing the negative effects of motion blur due to handshake. While most cameras use an opto-mechanic approach and correct the motion by moving a lens element or the sensor, other solutions purely rely on algorithms in the signal processing to reduce the motion blur. We evaluate the existing standards, show the challenges and present our efforts in the characterization of an arbitrary stabilization system, including systems based on opto-mechanical components or pure signal processing.*

## Introduction

When capturing an image, the sensor is collecting light during the so-called exposure time. The less light in the scene, the longer the exposure time needs to be. If the imaging system is hand-held, the maximum allowed exposure time is limited by the motion blur in the image introduced by movement of the camera during the exposure. Even though we had great developments in the past, the sensitivity of camera systems can not be extended without limitations. Another option is the introduction of optical image stabilization systems. These opto-mechanic systems are integrated into camera systems and compensate the influence of motion in the system, therefore reduce the motion blur in the image.

Like for any other component in imaging, it is important to be able to quantify the performance of the optical image stabilization (OIS) system. While there is a standard from the CIPA (Camera and Imaging Products Association, Japan [2]), this standard was developed with D-SLR and system cameras in mind. As miniaturization makes a lot of progress in the last years, OIS systems are now also found in mobile imaging devices like smart phones.

To support the work of the ISO to establish an international standard for the measurement of OIS system, which potentially also includes mobile devices, we had a closer look at the CIPA DC-X011[1] standard and checked where and where not it can be applied directly to mobile imaging.

## Existing Standards

As far as we know, there is only one standard that describes the measurement procedure of the OIS performance. The CIPA DC-X011 standard is available in Japanese and English and provides a complete description of the required hardware, software and measurement procedures to evaluate the OIS performance.

### *Test setup*

The basic concept is to measure the motion blur in the image. The motion blur appears as a "bokeh" or an increased edge width. The device under test (DUT) has to reproduce a specific test chart under different lighting conditions. While the illumination level decreases, the camera compensates the reduced amount of light with a longer exposure time. A longer exposure time potentially increases the motion blur. Images are captured under a reference condition, which is basically a still, non-moving setup and a measurement condition, where the camera is moved or shaken in a controlled way.

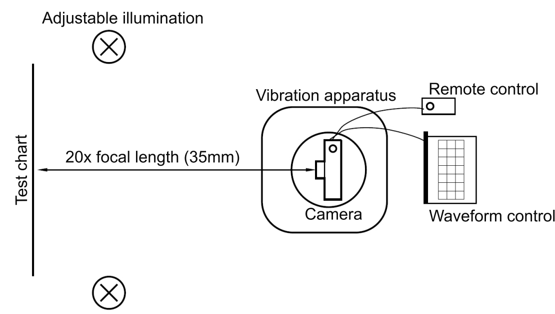


***Figure 1.*** *The setup used for the OIS performance measurement. The DUT is placed on an aparatus that can shake the camera in a controlled way. The camera is aligned towards a test chart. The illumination of the test chart can be controlled.*

### *Chart*

The chart consists of a repeated image of natural objects (a plate with fruits), placed on black and white tiles. These tiles have a strict horizontal and vertical orientation and the corners of these tiles are used for the analysis of motion blur (see Fig.3).

### *Hardware*

Beside the chart and the illumination, the most important hardware device for this test is an apparatus that can shake the DUT in a controlled and reproducable way. The CIPA certifies products that meet their requirements to make sure that the hardware used to shake the devices is actually able to simulate a natural handshake. For a certified device, a standard handshake can be obtained from CIPA and than be used during the measurement. This handshake shall represent the normal handshake of an average person using a camera.

### *Analysis*

The idea is to answer this question: *"How much longer can I expose the image while I do not see motion blur?"*

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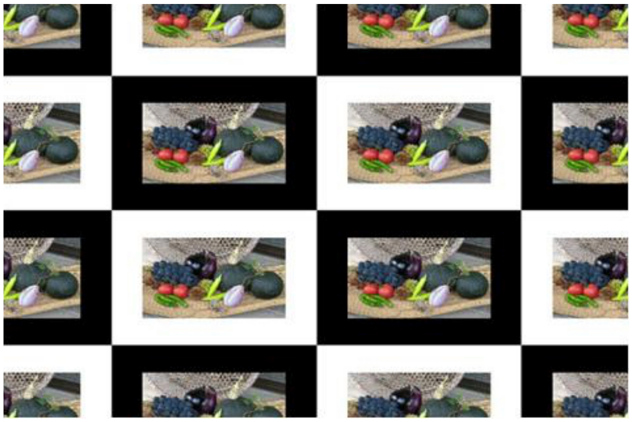

***Figure 2.*** *The used chart in CIPA DC-X011 standard.*

To answer this question, hundreds of images have to be captured and analyzed.

First we need to measure the motion blur at different exposure times. As the motion of the DUT varies over time and is not absolutely the same for each exposure, we need to capture several images while the camera is shaken und calculate the average motion blur.

The *motion blur* or, as it is stated in the CIPA standard, *bokeh* is measured on the corners of the black and white tiles. After several processing steps, which include morphological filter on a binary representation, the width of the remaining lines build by the edges is measured.

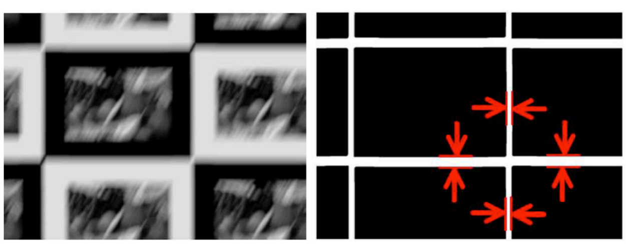

***Figure 3.*** *Analysis of motion blur in CIPA DC-X011* ***left****: An image of the test chart, captured with a device under test while it was shaken (cropped)* ***right****: The measurement of the motion blur, based on black and white corners in the chart. The image shows a binary representation of a filtered version of the original image.*

For the calculation of the OIS performance, we need the function "motion blur vs. exposure time" twice: Once with OIS turned on and a second without OIS. To obtain the function without OIS, we have two possibilities: Either these values are measured or they are simulated. In case motion blur is simulated, the expected motion blur in the image is calculated based on the average amplitude of the motion, the reproduction scale and the exposure time.

The measured edge width is influenced by general optical performance of and the signal processing in the DUT and added motion blur. To exclude the influence of the optical performance, an offset measurement is performed. This is basically a measurement at the given illuminance level with the OIS system turned off and without any movement of the device during the exposure.

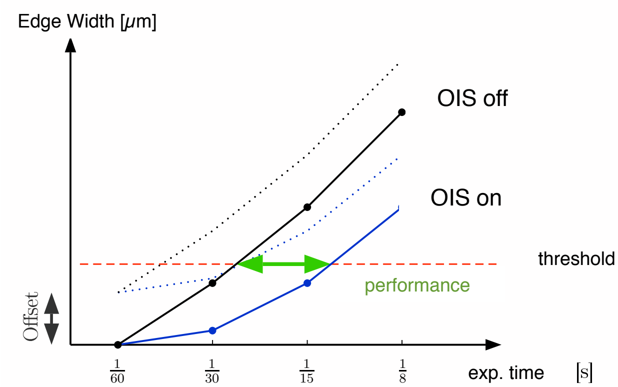


***Figure 4.*** *Calculation of OIS performance. The OIS performance is defined as the gain of exposure time for a defined threshold of motion blur in the image. For this calcuation two functions of motion blur vs. exposure time are necessary. Each measurement point is calculated based on a large set of images.*

As shown in Figure 4, OIS performance is calculated at a threshold value of acceptable motion blur based on the two offset corrected functions "OIS off" and "OIS on". It is measured as the difference in exposure time and expressed in exposure values (EV). So an OIS performance of 2EV means that with OIS turned on, the user can expose the image four times longer (2 EV) while the captured motion blur is still at or below the threshold.

## Issues of current CIPA standard

When implementing and using the CIPA-DC-X011 standard, we came along some issues that can make the measurement more difficult or less precise. These issues are more general, not only related to mobile imaging.

### *Chart design*

The CIPA DC-X011 standard describes a complete solution of testing, including test chart and the analysis process for images showing this test chart (see Fig.3).

The chart uses natural objects and black and white tiles in the background, the corners of the tiles are used for analysis. The contrast shall be 20:1 or higher.

When updating the ISO12233 resolution standard from the 2000 to the 2014 revision, the editors of this standard reduced the contrast of the used edges to 4:1 (60% modulation), as the high contrast chart "often yielded clipped count values in the finale image file, especially for processed image files." [3](see Fig. 5).

Due to this experience that has already been made, we consider the high contrast as a problem especially in mobile imaging, as these images show a high amount of sharpening. Figure 5 shows the edge spread function (ESF) for a D-SLR camera. Even for this camera sharpening leads to some clipping for the black and white edge. Devices with lower dynamic range and stronger sharpening (like most mobile phones) will show this effect even more.

### *Edge width measurement*

The key measurement for OIS evaluation is the edge width. The edge width describes how broad an edge found in the image

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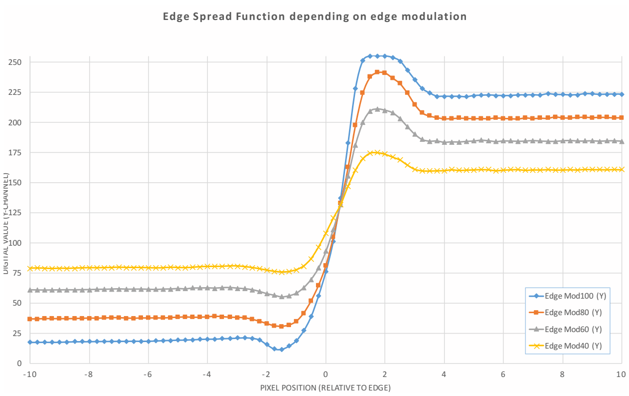


***Figure 5.*** *The edge spread function (ESF) measured for four different edge modulations for a D-SLR. (Canon 7D, JPEG, ISO100, default sharpening) Note that for the black and white edge (Mod100) the strong overshoot due to sharpening already leads to clipping, as it reaches digital values of 255. It can also be observed, that the edge width will vary depending on the edge modulation. In this examople, the edge width for a low contrast edge (Mod40) is higher compared to a high contrast edge (Mod100).*

gets due to optical performance of the imaging system plus potential motion blur. So the more blur we find in the image, the larger the edge width.

The edge width is measured under various different conditions. The increase of the edge width with added motion during the exposure and the decrease due to optical image stabilization is used for the calculation of OIS performance.

The described method in the standard uses a combination of several finite and morphological filter on grayscale and binary image representations. We consider this method as not very stable.

We implemented successfully an alternative approach to evaluate the edge width, which is based on the resolution measurement method using slanted edges as described in ISO12233[3]. This standard describes different methods to evaluate the resolution of an imaging system. The resolution is best described with the spatial frequency response (SFR). The so-called e-SFR method is based on a slanted edge in the object space. From the slanted edge, the edge spread function (ESF) is measured.

The ESF is used for calculation of the line spread function (LSF) as the first derivative of the ESF. The normalized Fourier transformation of the LSF is the SFR of the system under test.

So the ESF is the fundamental data the SFR analysis is based on. Using a projection along the slanted edge, the ESF as a one-dimensional edge profile can be obtained in a sub-pixel accuracy. A four time over-sampling is easily achieved. (see Fig. 6).

Once the ESF is available, the edge width can be derived from this data. A very common approach (also used here) is to evaluate the edge width as the distance in the edge profile for a 10% to 90% rise (see Fig. 7).

We created simulation data and show the results in Figure 8. We compared two methods, the CIPA method using the proposed analysis algorithm and an ideal version of the chart and, in comparison, we used the e-SFR method from ISO12233 and applied this on an ideal version of the TE261 chart as shown in Figure 9. Both ideal images have been blurred using the same filter. As the

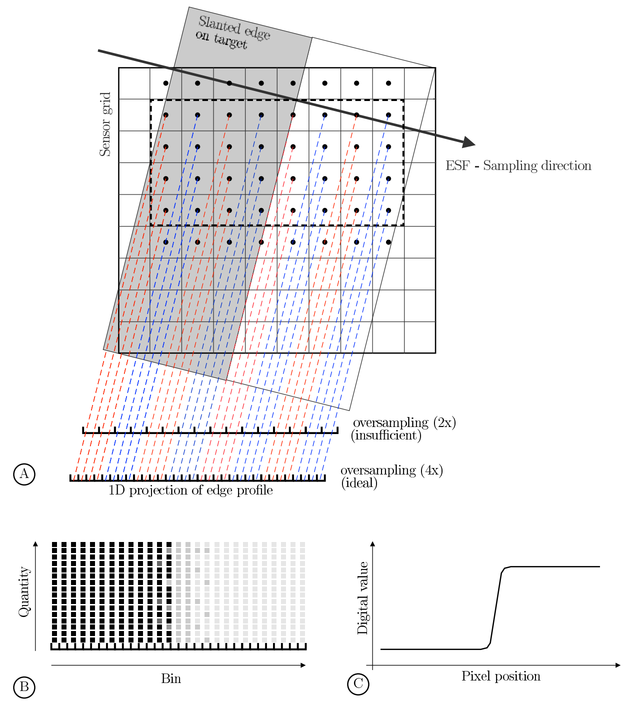


***Figure 6.*** *The ISO12233:2014 e-SFR method to obtain the ESF.* ***A*** *- The region-of-interest (ROI) is located around the slanted edge. The 2D pixel array is projected along the detected slanted edge onto a set of bins. This binning process is performed with a 4x oversampling, so four times more bins than pixel columns are used.* ***B*** *- As a result of the binning process (A), all pixel are reordered according to their distance to the edge in the image. Each bin represents a different distance to the edge in the image.* ***C*** *- The average of all digital values per bin results in the edge spread function ESF.*

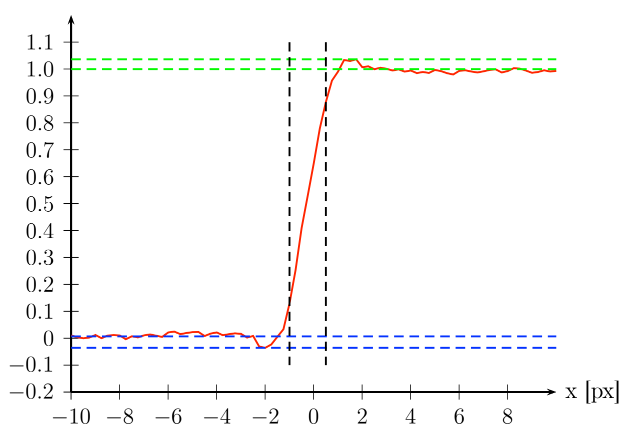


***Figure 7.*** *Edge width derived from the ESF. The edge width (distance between black dotted lines) is defined as the distance in pixel between the position within the ESF, where the level reaches 10% and 90% of the full amplitude, exclusing possible over- and undershoot from sharpening.*

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edge contrast is different, also the result is slightly different. Then we started to add noise with increasing variance. We can see that the CIPA approach is stable for a lower amount of noise, while it significantly and rapidly increases with increasing noise level. The e-SFR approach is more stable here.

Additionally, we used these images and applied a simple noise reduction onto these images by using the "Remove Noise" function in Adobe Photoshop. Also in this case the e-SFR approach is more stable while the CIPA approach varies for different noise levels.

We see several advantages of using the slanted edge approach over the very specific CIPA DC-X011 approach:

- **Chart Design** The described method in the CIPA standard is very specific to the used test chart, also specified in that standard. This limits the flexibility to use different chart layouts and designs.
- **Comparability** The slanted edge approach is well defined in the ISO12233 standard and used for a long time in the imaging industry.
- **Runtime** At least the reference implementation used for the CIPA standard is quite slow, so the analysis of several hundred images (which are easily achieved in a complete measurement) take several hours to compute. The slanted edge approach can be optimized that way, that it is significantly reduced (as shown in Section *"Results"*, this was 25 times faster).
- **Robust** The slanted edge approach uses all rows of a ROI to compute the ESF. Due to this averaging process, the influence of noise on the measurement results is reduced.

## Issues for mobile devices

While issues in the previous section are more general to all kind of imaging devices, we also found issues more specific to special cases in mobile imaging.

### *Fully automatic mode*

Unlike system cameras or high-end compact cameras, only a few mobile phones on the market allow the user to control the camera settings. This makes sense, as the user should not care much about ISO speed, exposure time or manual exposure compensation. For the measurement of an OIS system, this can be a problem.

At least with the end-user firmware and camera control software, the OIS can not be turned on and off. So for the calculation of the OIS performance, we can not measure the "worst-case" (shaking DUT without OIS). Even though we can estimate it, for the estimation a lot of technical details of the DUT are required which can be hard to obtain, as technical details about the camera are not always available for mobile phones.

### *Digital image optimization*

Beside the possibility to turn OIS on or off, the *fully automatic mode* of most mobile phones also means that the user does not have any influence on the exposure. For the measurement, it would be desirable to keep the aperture and the ISO speed constant and to control the exposure time via an intensity change in the illumination. Without the possibility to set the ISO speed manually, the device will increase the ISO speed with decreasing

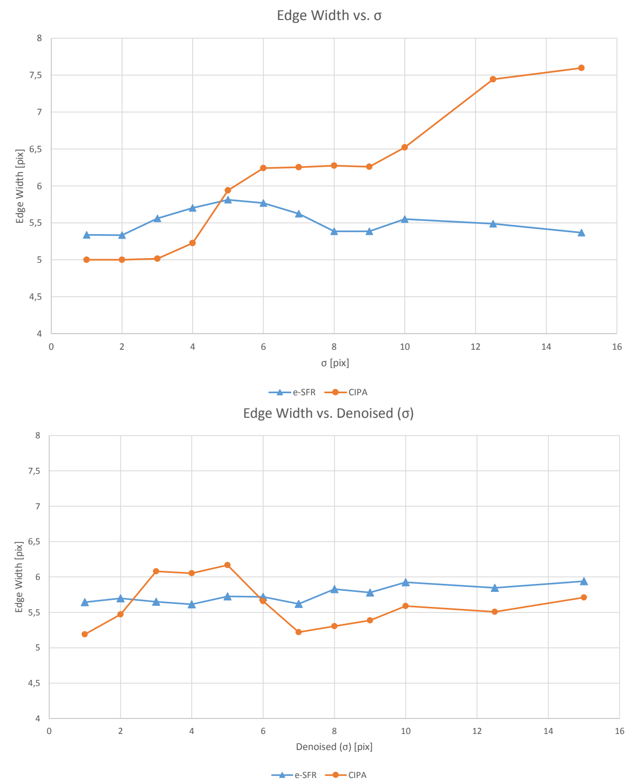


***Figure 8.*** *Comparison on simulated image data. **e-SFR** Using a perfect image of the slanted edge chart (Fig. 9), the image is blurred and then different amount of noise is added. **CIPA** Same processing for blur and added noise as in e-SFR, but with the CIPA chart (Fig. 3) **top**: Adding noise only; **bottom**: Adding noise and then apply Reduce Noise in Adobe Photoshop.*

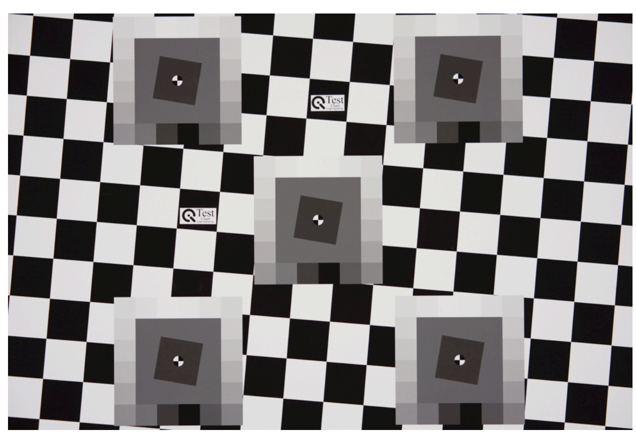

***Figure 9.*** *The used testchart for this paper. The slanted edges allow the measurement of the ESF according to ISO12233:2014, the background provides enough contrast for the AF algorithms. Gray patches allow a linearization with the actual measured OECF.*

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light intensity to keep the exposure time in an acceptable range for hand-held photography.

In Figure 10 we show the exposure behavior of the Apple iPhone 6s Plus (a mobile device with OIS) in comparison to the Apple iPhone 6s (without OIS). We see that at bright light conditions both devices expose with the same combination of ISO speed and exposure time. When reducing the illuminance of the scene, the device with OIS can remain on a lower level of ISO speed for all lighting conditions. The longest exposure time the device will select is 2 EV longer compared to the device without OIS, so it can expose four times longer. Therefore it can also keep the ISO speed two steps lower, which keeps the noise on a lower level as shown in Figure 10.

An increase in ISO speed means that the device in most cases shows more noise, which triggers an increase in the digital noise reduction. So beside the increase in motion blur, the images can also show noise, texture loss, different level of sharpening and artifacts that all potentially interfere with the measurement. So an increase in the measured motion blur can also be caused by a reduction of sharpening due to increasing ISO speed. This behavior can make a measurement more complex.

### *Different handshake for mobile phones*

The only defined and standardized handshake is the data available from the CIPA. This handshake has been measured in respect to simulate an average handshake that the DUT has to deal with when handheld. From our perspective, there is no reason to doubt the correlation between simulation and real hand shake for typical cameras. For mobile phones, this handshake might not be suitable. Compared to a camera, a mobile phone is normally significantly lower in its weight and the way the user holds it during exposure is different. While most cameras have a dedicated release button, todays mobile phones are mainly operated by touch buttons. The user does not slowly press the button, but tips the surface of the touch screen. Even though we did not investigate this in more detail, we assume that the hand shake for a mobile phone is different and that the motion introduced by the tap on the screen can not be neglected.

### *Difference in viewing conditions for mobile imaging*

The threshold that is used for the OIS performance calculation according to CIPA DC-X011 is defined as $63\mu m$. This value has been created based on a research project, where observers had to judge a lot of printed images in the size of a postcard. The images showed different level of blur and as a result it was shown that this $63\mu m$ is the limit where people see the blur.

The usage of images has changed over the years and only a small fraction of all captured images are printed at all. So while the threshold might be acceptable for the classic approach of photography, where results are printed image in postcard size, it might not be in todays viewing conditions in mobile imaging.

### *Non-global shutter*

Larger cameras normally feature a mechanical shutter in front of the imaging sensor. So the shutter is open during the exposure and blocks the light before and after, so the sensor can be reset and read out. The time the shutter is open is the exposure time. To reduce size and complexity of the camera, small camera modules, as used in mobile phones, mostly do not have a mechan-

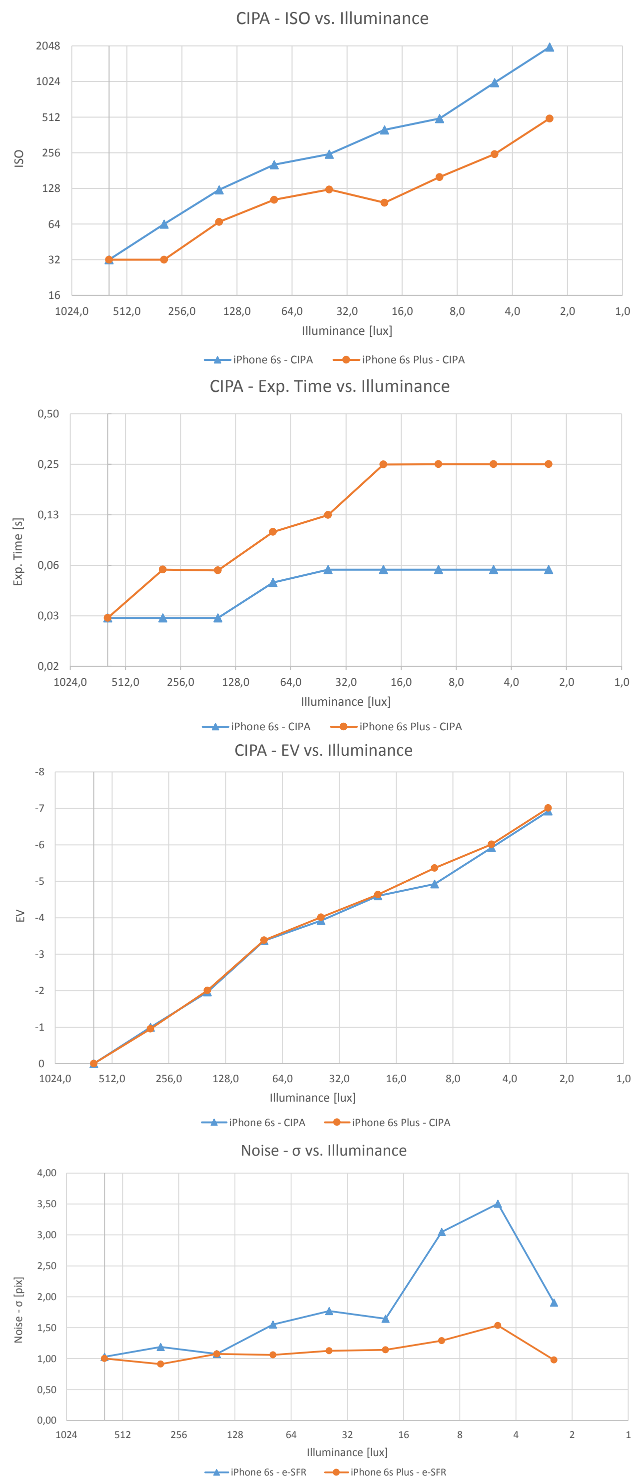


***Figure 10.*** *The exposure behavior of the Apple iPhone 6s (no OIS) and the Apple iPhone 6s Plus (with OIS). Measurement performed on CIPA chart with decreasing illuminance. For both devices the exposure is the same. The device with OIS system, allows a longer exposure time, while the system without the OIS has to increase the ISO speed. We can see that the engineers at Apple assume that the OIS system compensates 2EV of expsosure, so the exposure time can be four times longer.* ***bottom:*** *Noise measured as standard deviation on gray patch. As expected, the noise is higher for the device without OIS.*

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ical shutter. As in this case the light hitting the sensor can not be blocked for the read-out, the sensor is not exposed and read-out all at once, but row-by-row. So the global exposure time from the first row read out to the last row read out and the local exposure time of a single row is different.

As long as the manufacturer puts the correct data into the meta section of the image file, this is not a big issue. More of a concern are modern image optimization algorithms that combine several images for increasing the dynamic range or reducing the noise. The so-called 3D-noise reduction uses two or more images that are captured very closely after each other. In sections of the image that did not show moving objects, the images are combined to decrease the noise. So the de facto exposure time at different positions in the image can vary as it combines several images.

## Test setup

For this paper, we performed two complete measurements of OIS performance. In the next section we describe what both tests have in common and where they differ.

### *Common*

For both measurement procedures, the DUT is an Apple iPhone 6s Plus (iOS Version 9.0). The DUT is mounted onto a hardware solution that can shake the camera in a controlled way (see Fig.11). The used hardware is certified by CIPA that it is suitable for this purpose and that it can reproduce a simulated handshake. The simulated handshake that was used, is the official CIPA handshake that can be obtained from the CIPA for certified hardware solutions.

***Figure 11.*** *The hardware aparatus with the DUT. The hardware allows a movement with six degrees of freedom, so pitch, yaw, roll and translation in X, Y, Z direction. The device shakes the camera with the standard handshake as published by CIPA. The mobile phone camera is mounted that way, that it can capture images of the test chart. The image shows a mechanical "finger" that can be triggered from control software to press the release button. In the final measurement, this was replaced by a smaller solution that can trigger the touch button directly.*

For each measurement, 1890 images in full resolution have been captured. We used nine different illuminance level, for each level 200 images were captured. Additionally ten images were captured for each intensity without any handshake to calculate the reference offset. These many images have been captured as the handshake is changing over a period of time and the motion during the exposure time is not the same for every image. Using 200 images, we get a good and stable average value.

The light was formed by a halogen light source, filtered to daylight (CCT of 5000K). The intensity was changed by using neutral density filter (in front of the light sources) and by varying the distance of the light source to the chart. A maximum allowed non-uniformity of 10% over the entire chart was always given.

The distance between chart and camera was 580mm in both cases, which equals 20 times of the equivalent full-frame focal length of the DUT.

The needed information about the exposure time was extracted from the EXIF header of each image. The reported ISO speed value and exposure time value in the results is the average over all 200 images, as it might vary slightly within the image set.

### *CIPA*

For the measurement according to CIPA DC-X011 we used the test chart as shown in Figure 3. The chart is 750mm in height, only a part of it has been used as the distance of chart to camera was set to 580mm (see Fig. 12 for an example image). The analysis has been performed with the reference implementation that is provided by CIPA to registered customers. The analysis of all images took around 15 hours on a standard PC.

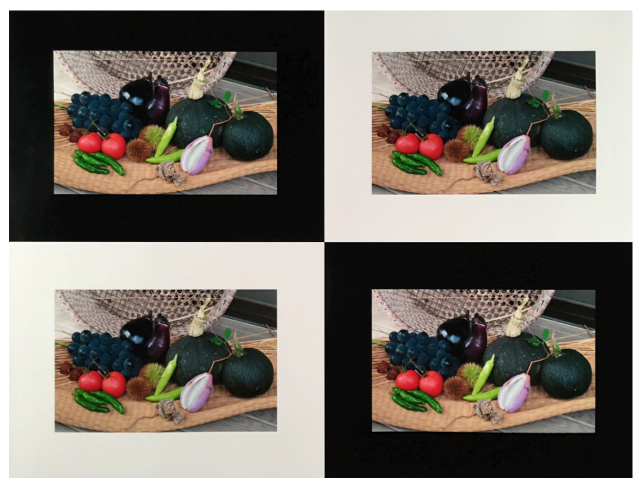

***Figure 12.*** *An example image of the CIPA chart as it was captured during the test with the given setup. The analysis is performed in the image center.*

### *e-SFR*

For the second measurement we used the test chart as shown in Figure 9. The measurement was performed based on all 20 slanted edges in the image (5 squares, 4 slanted edges each) . We measured the ESF for all 20 edges, calculate the average ESF for the image and derive the edge width from this ESF. The used software was developed for this purpose and follows the e-SFR algorithm as described in ISO12233:2014. The analysis of all images took around 35 minutes, so is around 25 times faster than the CIPA tool.

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## Results

Figure 13 shows the measured edge width versus the illuminance level. The edge width is calculated under the assumptions of the viewing conditions as explained in the CIPA standard for a postcard. The darker it gets, the wider the edge is spread. In the same graph, we see the theoretical edge width, as we can calculate it from the average exposure time, the average amplitude of the handshake during exposure and the calculated pixel pitch of the device under test. The theoretical edge width does not increase after a certain light level is reached, as the exposure time does not get longer below this light level. The edge width does increase below this point steadily, so this increase is not related to motion blur.

The absolute values of edge width differ between the two different methods. This is due to the fact that with the e-SFR method also the image corners are included into the measurement. The edge contrast found in the used chart is lower for the e-SFR approach, which also has an influence on the measured edge width.

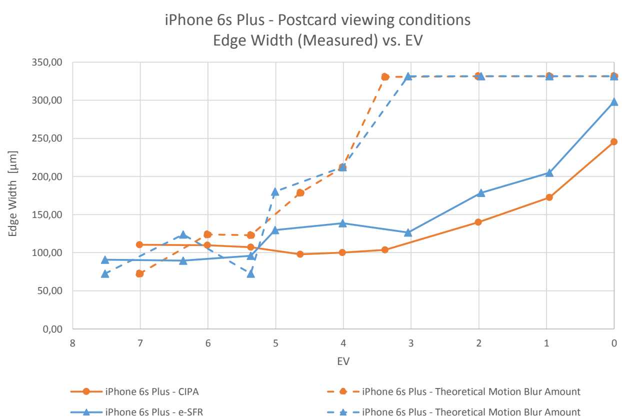


***Figure 13.*** *The measured edge width (under assumed postcard viewing condition) vs. illuminance (expressed in EV) for CIPA and e-SFR method. The dashed lines represent the theoretical motion blur amount, calculated based on the exposure time, average amplitude in the handshake during exposure and calculated pixel pitch of the DUT. The theoretical data remains constant for low light, as the exposure time does not increase after this. Even if the exposure time remains constant, the measured edge width increases at low light. So the edge width is not only influenced by the exposure time, but also by image processing.*

To see the influence of the signal processing, we performed the same measurement procedure also for the Apple iPhone 6s, a mobile phone without OIS, but very close in its processing and other hardware to the Apple iPhone 6s Plus used in the measurement of OIS performance (see Fig.14). We see that the CIPA approach shows a significantly higher edge width compared to the e-SFR, while the e-SFR results seem to reflect the subjectively perceived image quality better. The measured edge width is way above the theoretical motion blur. For both measurement approaches the edge width is higher compared to the results of the device with OIS, which was expected.

In Figure 15 we show the results as they should be presented according to CIPA DC-X011. Both, the measured edge width and the theoretical edge width have been corrected by the reference offset amount. So this graph should show the motion blur only,

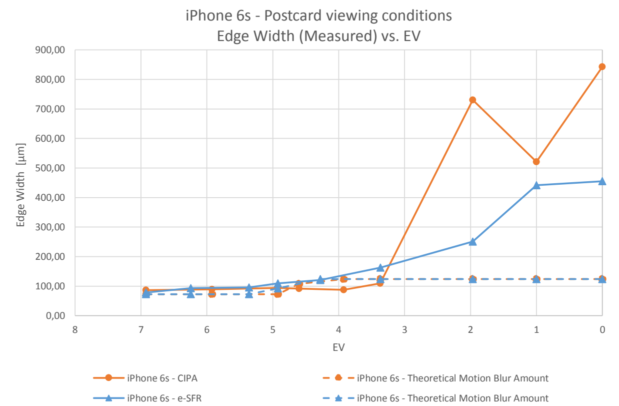


***Figure 14.*** *The results of OIS performance measurement for a DUT without OIS (Apple iPhone 6s). Test environment is identical, so can be directely compared to Figure 13. The theoretical motion blur amount is lower compared to the device with OIS, as the used exposure time is shorter. The increase in edge width is purely relying on the image processing, as exposure time and motion remain constant at lower light level.*

as all other aspects which could increase the edge width are corrected by the offset. As a result, we see that the increase in the edge width due to motion blur is very low, also in both measurement approaches. According to this data, the OIS performance according to CIPA would be 5EV and with the e-SFR approach for the analysis, it would be larger than 5EV. These are quite large number and is much higher to what we would expect from the device. Same measurement with a Sony NEX7 with SEL50mmf1.8 lens showed a performance of 2.94EV. As stated in Figure 10, the exposure setting is tuned that way that it assumes a win of 2 EV due to the OIS.

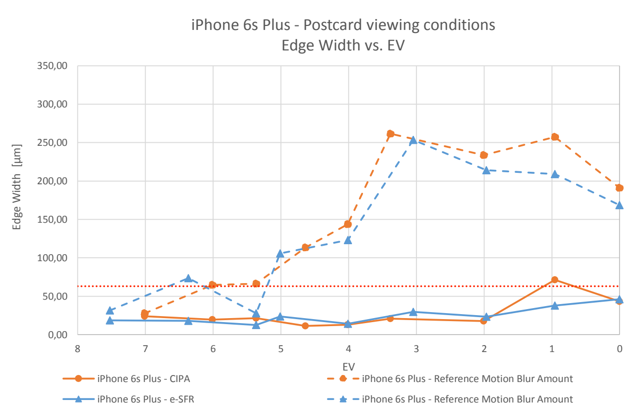


***Figure 15.*** *The offset corrected edge width vs. illuminance (expressed in EV). For each illuminance level, a reference measurement without movement of the DUT has been performed, the measured edge width on these images is used as offset. That way it should only show the increase in edge width due to motion blur, as the increase due to image processing should be in the offset. The OIS performance according to CIPA DC-X011 would be the difference between the matching functions at* $63\mu m$ *(red dotted line).*

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## Conclusion

An optical image stabilization system has big benefits for the user in low light situations. In these situations, the exposure time can be increased, so the camera collects enough light while possible negativ influence of hand shake is reduced.

The standard CIPA DC-X011 was developed and is suitable for the evaluation of cameras which allow the user to make several settings and allows the user to activate and deactivate the OIS system. The standard can describe the performance of the optical part and how much the OIS reduces motion blur in the image.

For mobile imaging this approach has some difficulties. For a mobile phone camera, it is very hard to separate the different aspects that have an influence on the image quality.

Our proposal is to extend the measurement of OIS performance by other aspects of image quality like noise, texture loss and color rendition. That way, the OIS performance measurement gets closer to a low light performance measurement, which is basically what we want to do. As ISO is working on a low light performance measurement standard anyways, we would propose to combine a possible OIS performance measurement ans low light performance measurement standard.

## References

[1] Standard of Camera & Imaging Products Association, ”CIPA DC-X011-2012 Measurement and Description Method for Image Stabilization Performance of Digital Cameras (Optical Method)” , English translation: CIPA DC-X011Translation-2012

[2] Camera & Imaging Products Association (CIPA), http://www.cipa.jp

[3] International Organization of Standardization, ”ISO12233 Photography - Electronic still picture imaging - Resolution measurements”

## Author Biography

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