Device and algorithms for camera timing evaluation

Lucie Masson, Frédéric Cao, Clément Viard, Frédéric Guichard
DxO Labs, 3 rue Nationale, 92100 Boulogne Billancourt, France

ABSTRACT

This paper presents a novel device and algorithms for measuring the different timings of digital cameras shooting both still images and videos. These timings include exposure (or shutter) time, electronic rolling shutter (ERS), frame rate, vertical blanking, time lags, missing frames, and duplicated frames.

The device, the DxO LED Universal Timer (or "timer"), is designed to allow remotely-controlled automated timing measurements using five synchronized lines of one hundred LEDs each to provide accurate results; each line can be independently controlled if needed. The device meets the requirements of ISO 15781[1].

Camera timings are measured by automatically counting the number of lit LEDs on each line in still and video images of the device and finding the positions of the LEDs within a single frame or between different frames. Measurement algorithms are completely automated: positional markers on the device facilitate automatic detection of the timer as well as the positions of lit LEDs in the images. No manual computation or positioning is required.

We used this system to measure the timings of several smartphones under different lighting and setting parameters.

Keywords: Image quality evaluation, timing measurement, exposure time, electronic rolling shutter, frame rate, digital photography

1. INTRODUCTION

Precise control of camera timings is very important in the art of photography. There is of course the exposure time (or shutter speed), which the photographer must carefully choose depending on the subject and the desired rendering. But there are other time-related phenomena that influence the rendering, on times the photographer sometimes cannot choose, such as the shutter release time lag (i.e., the delay between pressing the camera trigger and the actual image capture), the ERS, and for videos, the frame rate and missing or duplicated frames.

Rolling shutter in particular is an important source of time-related effects in photos and videos. Most CMOS sensors have a rolling shutter, which is a method of acquiring an image without exposing every pixel on the sensor at the same time; instead, image acquisition is performed one line after another. As a result, different parts of the image are not recorded at exactly the same time, which leads to unpleasant effects on images (or videos) if the scene or the camera is moving. A fast-moving camera, or fast-moving subjects with a speed roughly the same as the rolling shutter, can cause still-image distortions or "jello effect" vibrations in videos. And if some camera configuration parameters (exposure, focus, etc.) are modified during shooting, the resulting image can contain parts with different exposures or sharpness. There is ongoing research on compensation for or elimination of rolling shutter[2], [3], [4].

The development of image stabilization systems, as measured by Cormier *et al.*[5], is also related to these timings: such systems permit longer shutter times by reducing motion blur, which also reduces the noise in images. And because rolling shutter deforms images, it can influence stabilization, or perception of stabilization, too. A fast, easy, and repeatable protocol is needed to characterize these timings.

1.1 Scope

This paper describes the device and algorithms used to measure the different timings of a camera or a video recorder. We first describe the instrument, with its specifications, and the algorithms used for several measured timings. We also describe the automation, and then discuss the accuracy of the method, using the results from several examples.

Among the advantages of the proposed method:

- The device is easy to use, requiring little hardware and few manipulations;

Corresponding author: cviard@dxo.com

- It is accurate, and the user can choose level of accuracy;
- It can be used to measure any still camera or video recorder.

The described measurements assume that the exposure time is the same for all pixels; this method should not be used if this condition is not fulfilled.

1.2 Prior art, existing standards

The proposed device is compliant with ISO 15781[1]; this standard normalizes the measurement of time lags (shooting time lag, shutter release time lag, shooting rate, etc.). Bucher *et al.*[6] describe how to use this device so as to specifically follow this standard. Another ISO standard, 516[7], is related to camera timings, but its test methods are designed for routine manufacturing and quality control, and require dismantling the camera, and thus is outside the scope of our protocol. These two standards are the references for timings in the CIPA[8] specification guidelines for digital cameras.

The IEEE Standards Association is developing a standard related to timing measurements. This is the continuation of the standard for Camera Phone Image Quality project (CPIQ)[9], [10]. We are taking active part in this development, and our plan is to be compatible with the future standard.

Our device has more LEDs than other existing solutions available to businesses[11], allows automatic and fast measurement, and avoids the use of complex measurement protocols. By contrast, several rolling shutter calibration protocols require complicated manipulations: for example, in the protocol of Geyer *et al.*[12], the lens of the camera needs to be removed, and in Oth *et al.*[13], a known pattern must be positioned and moved in front of the camera. Those methods would be difficult to apply in an industrial setting, thus the need for a simpler system.

2. DESCRIPTION OF THE DEVICE

The DxO LED Universal Timer (or “Timer”), shown in Figure 1, is composed of five lines of one hundred LEDs each, which light up sequentially. At any given moment, there is always one and only one lit LED on each line. When an LED is turned off, the next LED is turned on, cycling when the end of the line is reached. On any given line, each LED is lit for exactly the same amount of time, and the total time to light all of the LEDs is given in milliseconds on the numeric display to the right of each LED line. Each LED remains on exactly one 1/100th of the total displayed line time. Lines with the same period are synchronized, meaning that the first LED of these lines is lit at exactly the same time.

Figure 1: The DxO LED Universal Timer with five LED lines of 100 LEDs each. Six positional markers are used to automatically detect the timer in images; results are displayed on the right.

ISO 15781 requires that a timing device have an accuracy of at least 1ms and be capable of measuring times up to 10s. This device exceeds these requirements, as the lighting time for LEDs is adjustable from 0.01ms to 100ms, leading to measurement times up to 10s with a maximum accuracy of 0.01ms for a single frame. The selected LEDs light up and turn off in 320ns, which corresponds to 3.2% of the minimum lighting time.

Each measurement is based on the number and the position of detected lit LEDs in an image, with, for example, the exposure time of the image deduced from the product of the number of visible LEDs and the lit time of each LED.

Rolling shutter, time lag, and frame rate are computed by comparing the position of LEDs on different lines in a single image or the positions of LEDs on a single line in different frames. For rolling shutter measurements, the sensor lines (orthogonal to the direction of the rolling shutter) must be aligned with the timer lines. Figure 10 below shows the timer shot with a camera equipped with a rolling shutter.

The accuracy of the measurements depends on the selected period of the LED lines. Exposure time measurement has best accuracy when the line period is only slightly larger than the exposure time. It can therefore be useful to set lines at different periods, because then a very good accuracy can be obtained for a single still image, or for only one video, even if the value of the measured timing is not even approximately known before shooting.

The six positional markers allow the timer to be automatically detected in any scene, and the use of LEDs in bar graph form allows for automatic detection of the lit LEDs.

Furthermore, the timer and its settings can be remotely controlled by a computer via USB, which makes it easier to follow shooting protocols. The timer parameters can be remotely retrieved and adjusted.

3. MEASUREMENT ALGORITHMS

3.1 Measuring times with the timer

Several time measurements can be done with the timer; we give only a few examples here, but other uses are possible. The sample results below were obtained by using DxO Analyzer v5.2 software. The computation of time lags (i.e., shutter release time lag and shooting time lag) and their shooting protocols are described in a separate paper[6].

The diagram below shows three intervals, plus exposure time, during the acquisition of a video on a digital camera:

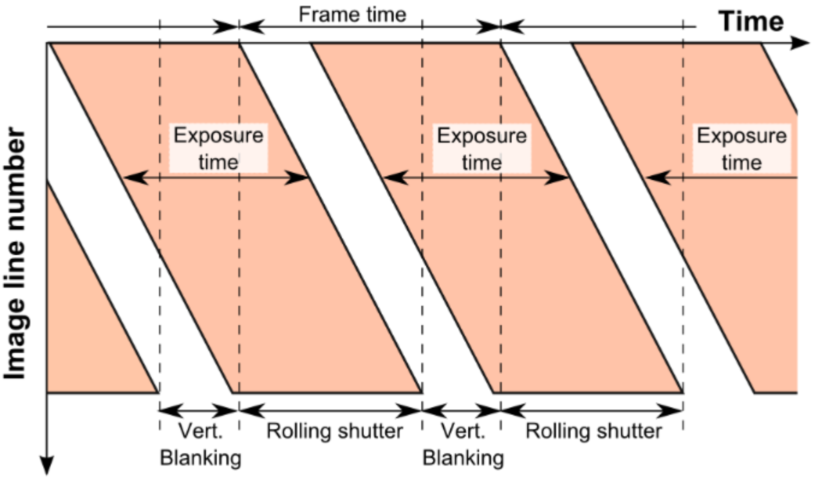

Figure 2: Diagram of the different timings measured for a video.

Exposure time is computed by counting the number of lit LEDs on each line, computing the associated time, and returning the average for the more accurate lines (the lines that have a period just slightly longer than the measured time).

Thus for an LED line, with $Calibration$ as the time required to light all the LEDs, and N_{LED} as the number of lit LEDs, exposure time is calculated as:

$$T_E = N_{LED}.Calibration/100 \tag{1}$$

If different calibrations are chosen for individual lines, the results from lines at the highest calibration with at least one LED not lit are averaged to obtain the final result.

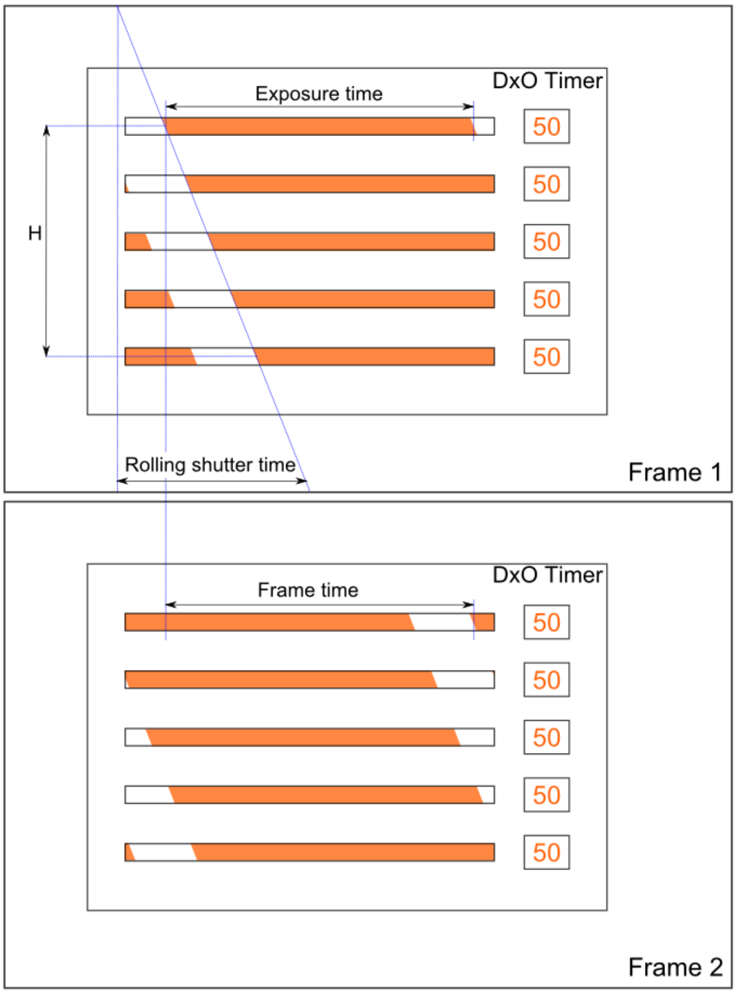

Figure 3: Measuring exposure time, rolling shutter time, and frame rate using two consecutives frames.

Rolling shutter time is defined as the time needed to expose all sensor pixel lines. To measure rolling shutter time, the sensor lines (orthogonal to the direction of the rolling shutter) must be aligned with the timer. Measurement uses the position of the first lit LED of two lines with the same calibration (and thus synchronized). Thus:

$$T_{RS} = ((L_2 - L_1)\,\mathrm{mod}100).Calibration.\frac{Height}{100.H} \tag{2}$$

with L_i as the first lit LED on line i, H as the number of pixel lines between the two LED lines, and $Height$ as the height of the sensor in pixels.

On video, the time difference for the same LED line is used to determine the time between two consecutive frames:

$$T_F = ((L_{k+1} - L_k) \bmod 100).Calibration/100 \tag{3}$$

with L_k as the first lit LED on frame k. Frame rate is then computed as $1000/T_F$. If the next frame is a duplicate of the current frame, the time will be null.

Vertical blanking is the difference between frame rate and rolling shutter:

$$T_V = T_F - T_{RS} \tag{4}$$

It is also possible to perform statistical computations for video frames: if the average time between frames (with outliers removed) is T_F, then finding missing frames is straightforward. If the time between two frames is $(n+1).T_F$, this means that n frames have been lost between the two.

While computing rolling shutter and frame rate from a single pair of LED lines, it is not possible to determine if the lines have cycled one or several times between the pair. Thus it may be useful to use several LED line calibrations: a slow calibration will yield a rough estimation of the measured time, while a fast calibration will refine the result.

Supposing a slow calibration C_S is used to compute a rough estimation of frame time T_F^S, and a fast calibration is used to compute a refined frame time, T_F^F, the final frame time is:

$$T_F = T_F^F + \left| \frac{T_F^S - T_F^F}{C_s} \right| .C_s \tag{5}$$

This same method can be used to compute a more refined estimate of rolling shutter time.

3.2 Detection of lit LEDs

As shown in the time measurement algorithms above, two values, the number of lit LEDs and the position of the first lit LED, must be extracted from the LED lines in order to perform the measurements.

The positional markers make it possible to determine the position of each LED line in image. When this position is known, it is then possible to obtain the two values from each LED line, as follows:

The first step is to crop each LED line separately.

Figure 4: Crop of one LED line.

The second step is a morphological closing, which removes the separation lines between LEDs. The mask for the closing is half the width of an LED, in pixels.

Figure 5: Crop of an LED line after closing.

The third step is to binarize the crop. The threshold is selected so to have only one to three different segments on each pixel line. Pixel lines with only one segment (usually on the top or bottom of the crop) are ignored in the next steps.

Figure 6: Binarization of the crop of an LED line.

Because rolling shutter also affects each lit LED, as seen on the first lit LED on Figure 4, it is not possible to take the average of all the pixel lines together when computing the two final values; instead, the two values must be computed for each individual pixel line.

For each pixel line, the position of the first and last lit LEDs is determined by looking for non-null gradients on the line. There can be one or two of these gradients, depending on whether the first LED on a given line is also the first or the last lit LED, or not. In this first case, there is only one detected non-null gradient. The number of lit LEDs and the position of the first lit LED are computed from these gradient positions.

The final estimate of the number of lit LEDs is obtained via a robust averaging of the results for all pixel lines. The first lit LED L_j of each pixel line j is also computed and robustly fitted with a linear function $L_j = a.j + b$, and the final result is the estimated value for the mid-pixel line. These two values can then be used with different timing measurements to avoid having to manually count lit LEDs.

3.3 Workflow for automatic measurements

The algorithm for reading LED line content along with the defined timing measurement equations are the two main elements of the overall calculation workflow for processing of still images or video files. Below is a description of the different steps to automatically compute video timings from a video file.

First, the positional markers need to be detected in images or frames. Here we use a common detection method derived from the Harris and Stephens corner detector[15]. Then the LED lines are cropped and read, and two values are computed for each LED line — i.e., the position number of the first lit LED and the total number of lit LEDs on the line. Still image measurements (shutter speed, rolling shutter, etc.) are computed from these values. If the input is a video, each frame is processed and the results per frame are stored. When all frames are processed, the video measurement results (frame rate, missing frames, etc.) are computed. Still frame results are also robustly averaged to take into account the multiple frame results of the video.

The workflow for video measurement is shown in Figure 7 below.

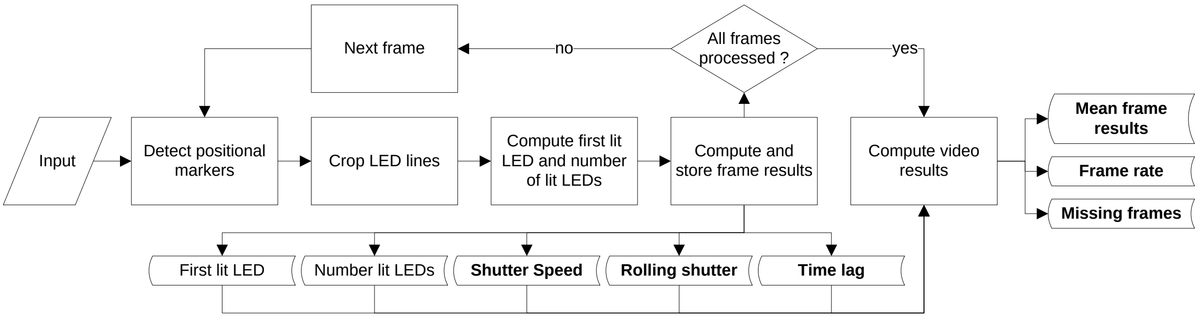

Figure 7: Video measurement workflow.

4. MEASUREMENT ACCURACY

The first contributor to inaccuracy is that the number of lit LEDs is by construction a whole number. The same is true for the position of the first lit LED. Furthermore, the first- and last-lit LEDs may be considerably less bright than others, because their total lit time was almost certainly only partially captured during the exposure time of the camera. Thus the greatest measure of accuracy is one LED for the position of the first lit LED. It is also one LED for the number of lit LEDs, because an LED is usually not detected if less than a third of its lit time is captured during exposure time. Conversely, it is usually detected as lit if more than two-thirds of its lit time is captured.

Thus the accuracy of the measurement in milliseconds depends primarily on the selected calibration of the timer, which means that for example the equation for exposure time measurement accuracy is:

$$T_E = N_{LED}.Calibration/100 \pm Calibration/100$$

Frame time and rolling shutter time computations use two LED lines, which means that their accuracy is ±2 LEDs. For rolling shutter, the positions of the line pair also influence the accuracy: accuracy is better if a large portion of the image is between the LED lines used for measurement. Thus for good accuracy, it is important to correctly select the timer calibration to align with the measured times.

There is another factor contributing to inaccuracy. While measuring very short exposure times on cameras with a mechanical shutter, the accuracy of the measurement may be lower than the precision value given above, for two reasons:

First, the measurement implies that the exposure time is the same for all pixels. This is not always true for a mechanical shutter at its maximal speed, and (for example) the bottom of the image may have a longer exposure time than the center, as explained in ISO 516[7]. Thus at high speeds, the results may vary depending on the position and the size of the timer in the image.

Secondly, the mechanical shutter does not open instantaneously, but rather opens and closes progressively. If this opening is on the same scale as the shutter speed, which is typically the case when the camera selects the shorter available shutter speed, the measurement will be impacted, in that the LEDs will have different exposure and blur in the image, making the results unusable. Figure 8 shows an example of a resulting LED line crop for the shortest shutter speed of a camera.

The measurement methods described in this paper should not be used for shutter speeds shorter than 5 times the maximum available shutter speed on cameras with a mechanical shutter.

Figure 8: Influence of the opening time of a mechanical shutter on the image of an LED line. The LEDs in the middle are more exposed than the LEDs on the ends.

5. SAMPLE MEASUREMENT RESULTS

Using our device in automatic mode, we performed different measurements on several cameras, using different shooting protocols. Here are several examples of use cases of the timer.

5.1 Adaptation to lighting conditions

We first tested the behavior of the cameras under different lighting conditions in order to check if the cameras adapted their exposure times and frame rates to the ambient light, and up to which exposure times. The timer was lit with tungsten bulbs ranging in intensity from 10 to 3000lux. We tested three cameras: the Apple iPhone 5, the Samsung Galaxy SII (SG SII), and the Sony Xperia Kyno (SE XK), which uses an older technology.

Table 1. Results of exposure time measurements (in ms) under different lighting conditions (in lux).

T_E (ms)	**10**	**20**	**40**	**100**	**160**	**400**	**800**	**1600**	**3000**
iPhone 5	41.7	41.7	41.7	33.5	33.3	33.2	25	8.4	6.6
SG SII	40.3	40.3	40.3	40.1	39.3	29.7	29.8	19.8	9.9
SE XK	30.3	30.3	30.4	33.6	33.6	33.6	30.2	19.1	10

Table 1 above shows the results. The selected timer calibration was 50ms for each LED line, leading to an accuracy of 0.5ms for each line. Averaging the five LED lines gives an accuracy of roughly 0.2ms.

The Xperia Kyno has a constant frame rate of 30fps, while the other two devices adapted their frame rates. The iPhone 5 operated at 24fps up to 40lux, and then switched to 30fps, while the SG SII operated at 25fps up to 400lux, and then switched to 30fps as well. Note also that the Xperia Kyno selected incorrect exposure times at low intensities, leading to over-exposed images at 100lux, and under-exposed images from 10 to 40lux. All cameras had under-exposed images at 10 and 20lux.

Reducing the frame rate allows a camera to shoot at longer exposure times when luminosity is low, leading to better adaption of exposure to environment, but not all cameras have this capability.

5.2 Adaptation to activation of the stabilization

We also checked if cameras automatically changed their exposure time when a stabilization option is activated. We tested one camera, the Samsung Galaxy SIII, and we shot images under the same luminosity and framing conditions, first with stabilization activated and then deactivated. This time we processed full-resolution still images rather than frames from videos, with the results shown in Figure 9. For the same scene, the camera chose an exposure time of 30ms when stabilization was on, and 50ms when stabilization was off. This difference in shutter speed did not occur under all shooting conditions, and was affected by the lighting and content of the image.

This camera does not have an optical stabilization system (OIS). Thus it is likely that the “stabilization” option consists in changing the camera parameters (shutter time, ISO speed...) to reduce motion effects. Reducing shutter speed will reduce these effects, at the cost of an increased noise.

Figure 9: The Samsung GSIII with stabilization on (left) and off (right). Calibration is 100ms for both images, meaning that exposure time is shorter when stabilization is activated.

5.3 Rolling shutter and resolution

We next measured rolling shutter time for the Canon 650D camera at different resolutions, with the results shown in Table 2 below. Selected calibration for the timer was 50ms for all lines, giving an accuracy of ± 1.2ms for the rolling shutter measurement (obtained from the one-LED precision for each of the two lines used for measurement and the one pixel precision for the position of the LED lines in image, per section 4 above).

Table 2. Results of rolling shutter for video per selected image heights.

Image height	480p	720p	1080p
T_{RS} **(ms)**	23.2	11.69	19.36

The results for 720p and 1080p video in 16:9 format are coherent: the more lines in the image, the more time needed to read all the lines. The result for 480p video in 4:3 format is more surprising: apparently less care was dedicated to this mode, which is less optimized, for a rolling shutter time that is longer than for 1080p videos. Clearly, this mode should be rarely used. This result also shows that the rolling shutter not only changes with the resolution, but also that the relationship between rolling shutter and resolution can be relatively complex.

5.4 Comparison of images taken with mechanical shutters and rolling shutters

Our last test compared images taken with and without rolling shutter. The Nokia Lumia 1020 has the particularity of having a global mechanical shutter along with a so-called “smart mode” in which several shots are taken during a very short time interval using an electronic rolling shutter.

Per Figure 10 below, we took two shots of the same scene with this camera, one in smart mode and the other in the default camera mode. The scene contains the timer, with all LED lines at 20ms, and a toy rotating propeller. Unlike the global shutter result on the right, the rolling shutter on the left shows a skewed propeller, and of course the rolling shutter effect is also visible on the synchronized LED lines of the timer. For this camera, the measured rolling shutter time is 30ms. The rolling shutter effect on the image of the propeller is even more apparent in Figure 11.

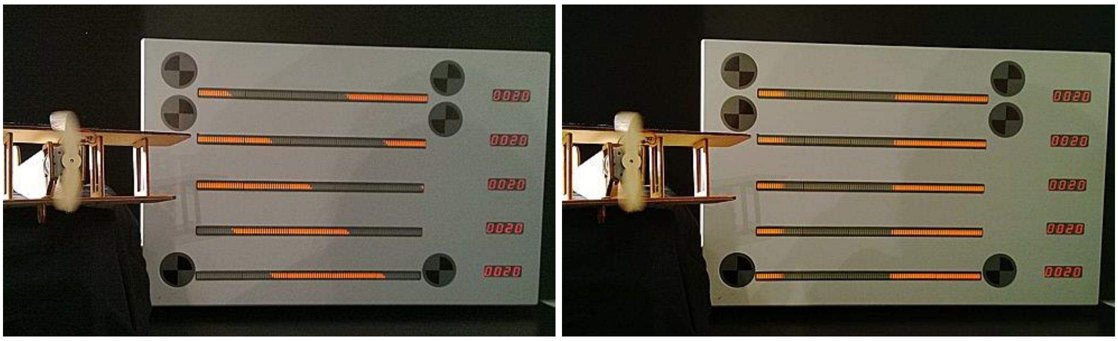

Figure 10: The Nokia Lumia 1020 in smart mode (left) and default camera mode (right). A rotating propeller was shot with the timer to demonstrate the effect of rolling shutter on moving objects. This camera has a global (mechanical) shutter, which is replaced by a rolling shutter in smart mode, because this mode requires a shorter shutter speed that can only be provided by an electronic shutter.

Figure 11: Close-up of the propeller as shot with the Nokia Lumia 1020 in smart mode using an electronic rolling shutter. The image of the propeller is deformed by the rolling shutter.

6. CONCLUSION AND PERSPECTIVES

We introduced a new device, the DxO LED Universal Timer, designed to measure the different timings of digital cameras by counting LEDs on images. LED bar graphs make it easy to count LEDs on the instrument, and counting was done automatically with advanced image processing algorithms. The high number of LEDs allows for great measurement accuracy, provided that the conditions of use are respected (i.e., identical exposure time for all pixels, and exposure time not on the same scale as the speed of a mechanical global shutter, if there is one).

We provided some examples of how to use our timer to check the behavior of several cameras under varying conditions (lighting, activation of the stabilization system, and video resolution). All results were obtained automatically without human processing of the images, and without opening or modifying the cameras. It was only necessary to select the desired shooting conditions (lighting, camera parameters), and then to take photos of the timer.

The standards for digital camera timing measurement are still evolving. We will continue to participate in these developments, and will follow the standards and recommendations when they are published. The timer is compliant with the existing ISO standard. It is also designed to be flexible, and will require only some adaptation of the algorithms presented in this paper, or the creation of new ones, to remain compatible with the standards as they evolve.

7. REFERENCES

[1] ISO 15781, "Photography — Digital still cameras — Measuring shooting time lag, shutter release time lag, shooting rate, and start-up time" (2013).

[2] Liang, C.-K., Chang, L-W., and Chen, H., "Analysis and compensation of rolling shutter effect for CMOS Image sensors," Proc. IEEE Trans. on Image Processing, vol. 17, no. 8, 1323–1330 (2008).

[3] Baker, S., Bennett, E., Kang, S., and Szeliski, R., "Removing rolling shutter wobble," Proc. IEEE Conference on Computer Vision and Pattern Recognition (2010).

[4] Jia, C., Evans, B. L., "Probabilistic 3-D Motion Estimation for Rolling Shutter Video Rectification from Visual and Inertial Measurements," Proc. IEEE Multimedia Signal Processing Workshop (2012).

[5] Cormier, E., Cao, F., Guichard, F. and Viard, C., "Measurement and protocol for evaluating video and still stabilization systems," Proc. SPIE 8653, Image Quality and System Performance X, 865303 (2013)

[6] Bucher ; F.-X., Cao, F., Viard, C., Guichard, F., "Electronic trigger for capacitive touchscreen and extension of ISO 15781 standard time lag measurements to smartphones," Proc. SPIE 9016, Image Quality and System Performance XI (2014).

[7] ISO 516, "Photography – Camera shutters – Timing" (1999).

[8] CIPA DCG-002, "Specification Guidelines for Digital Cameras" (2012).

[9] Baxter D., Cao F., Eliasson H., Phillips J., "Development of the I3A CPIQ spatial metrics," Proceedings of Electronic Imaging (2012).

[10] Standard for Camera Phone Image Quality (CPIQ) http://grouper.ieee.org/groups/1858/index.html, IEEE P1858

[11] Image Engineering LED-Panel http://www.image-engineering.de/index.php?option=com_content&view=article&id=76

[12] Meingast, M., Geyer, C., and Sastr, S., "Geometric models of rolling-shutter cameras," CoRR abs/cs/0503076 (2005).

[13] Oth, L., Furgale, P., Kneip, L., and Siegwart, R., "Rolling Shutter Camera Calibration," Proc. IEEE Conference on Computer Vision and Pattern Recognition (2013).

[14] DxO Analyzer v5.2 http://www.dxo.com/intl/image-quality-evaluation

[15] Harris, C., Stephens, M., "A combined corner and edge detector," Proc. Fourth Alvey Vision Conference (1988).