Electronic trigger for capacitive touchscreen and extension of ISO 15781 standard time lag measurements to smartphones

François-Xavier Bucher, Frédéric Cao, Clément Viard, Frédéric Guichard
DxO Labs, 3 rue Nationale, 92100 Boulogne Billancourt, FRANCE

ABSTRACT

We present in this paper a novel capacitive device that stimulates the touchscreen interface of a smartphone (or of any imaging device equipped with a capacitive touchscreen) and synchronizes triggering with the DxO LED Universal Timer to measure shooting time lag and shutter lag according to ISO 15781:2013. The device and protocol extend the time lag measurement beyond the standard by including negative shutter lag, a phenomenon that is more and more commonly found in smartphones.

The device is computer-controlled, and this feature, combined with measurement algorithms, makes it possible to automatize a large series of captures so as to provide more refined statistical analyses when, for example, the shutter lag of "zero shutter lag" devices is limited by the frame time as our measurements confirm.

Keywords: Image quality evaluation, Smartphone, Capacitive touchscreen, Shutter release time lag, Shutter lag, Shooting time lag, Latency, Autofocus speed

1. INTRODUCTION

Most users expect to capture the image they see when pressing the camera trigger, but most cameras have a noticeable delay between the moment the trigger is pressed and when the image is actually captured. This delay is particularly noticeable in candid, spontaneous, and action or sports photography.

Shooting time lag is the delay between the time the shutter is pressed and the time the image is acquired. The delay is caused by many-time consuming control operations within the camera such as auto-exposure, autofocus, and stabilization start-up.

This delay is a decisive criterion for buyers choosing an imaging device, and thus camera manufacturers continue to try to outdo one another by improving the autofocus algorithms, the lens designs, and/or the shutters.

ISO standard 15781, "Photography — Digital still cameras — Measuring shooting time lag, shutter release time lag, shooting rate, and start-up time,"[1] was recently published and defines several time lags as well as the methods for measuring them. This standard focuses almost exclusively on DSLR and DSC cameras, and proposes only simple measurement methods for devices with a physical shutter trigger.

Over the past few years, using smartphones as cameras has become very popular, and in fact the camera application is now one of their main selling points. Contrary to DSCs and DSLRs, most smartphones do not have a dedicated physical shutter button, but instead require the user to touch a specific area on the phone's capacitive touchscreen to take a photo.

1.1 Scope

This paper describes a novel capacitive device, the DxO Touchscreen Probe, that stimulates a touchscreen interface, and describes how this device facilitates measuring shooting time lag and shutter lag according to ISO 15781:2013[1]. As our measurements show, the device and the associated measurement method introduce a negligible random error as compared to the variations found for the measured imaging devices themselves. Our measurements also show that negative shutter lag is quite common among smartphones, and that there is a correlation between the exposure time and both the average value and the standard deviation (or other statistics) of the measurements.

1.2 Prior art, existing standards

We developed the DxO Touchscreen Probe and method to follow the newly-published ISO 15781:2013 standard[1]. This standard normalizes the measurement of time lags, in particular shooting time lag and shutter lag, and also proposes

Corresponding author: cviard@dxo.com

solutions for measuring those values for imaging devices that use a physical button for a shutter. This standard is the reference for timings in the CIPA[7] specification guidelines for digital cameras.

The IEEE Standards Association is developing a standard related to timing measurements as an extension of the standard pertaining to the Camera Phone Image Quality project (CPIQ[8], [9]). The authors of this paper are actively participating in this development, and the instrument described in this paper will be compatible with the future standard.

2. DESCRIPTION OF THE DEVICE

2.1 LED Timer

We performed the experiments described in this paper using the DxO LED Universal Timer. This timer, described in detail in a separate paper[2], is composed of five lines of one hundred LEDs. The LEDs light up sequentially on each line, and the periods of each line can be adjusted separately. The timer has two ports: a simple input port which allows an electrical signal showing the position of the LEDs at any given moment (e.g., the trigger point) to be sent from the DxO Digital Trigger (see the description in part 2.2 below) to be saved in the timer memory; the other is a USB port which allows the data to be sent to a remote computer and allows the procedure to be controlled via a remote computer.

2.2 DxO Touchscreen Probe

The design of the DxO Touchscreen Probe is inspired by the smartphone industry's capacitive touchscreen technology. A capacitive touchscreen measures the change in capacitance at its surface so as to detect the user's finger[4]. The device described in this paper employs this capacitance by connecting a thin sheet of metal placed on the touchscreen to the smartphone electrical ground, usually accessible via the smartphone's USB port (see Figure 1). The connection can be controlled by an electronic switch signal. The result is an electronically-controlled capacitive trigger that simulates a finger touching a smartphone touchscreen, as illustrated in Figure 2.

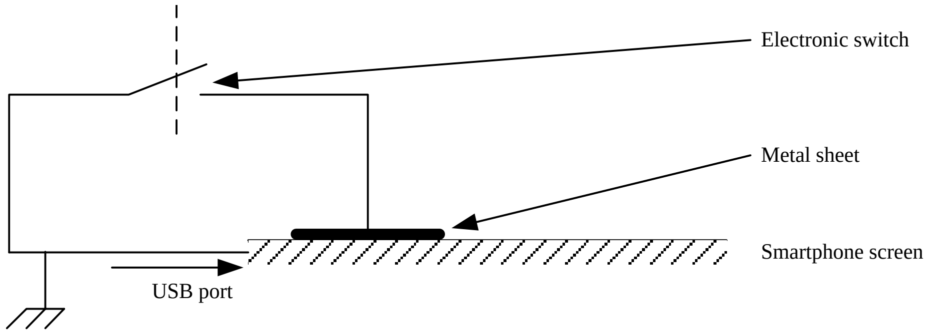

Figure 1: Electronic principle of the screen probe.

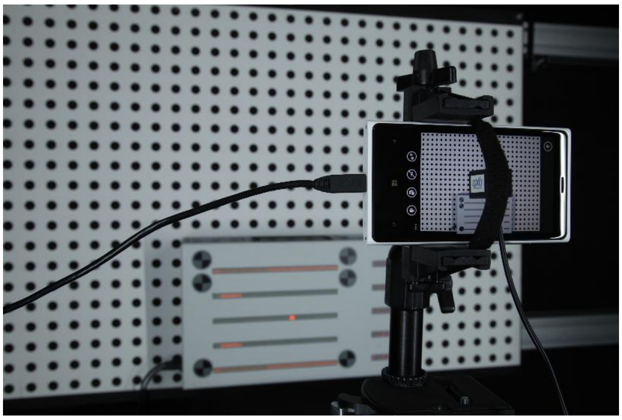

Figure 2: The DxO Touchscreen Probe on a smartphone touchscreen. The LED Universal Timer and a test chart are shown in the background.

The DxO Touchscreen Probe is controlled by the DxO Digital Trigger, which also generates the signal that is sent to the LED timer. The DxO Digital Trigger has several features:

- The duration of the signal can be set with an accuracy limited only by the DxO Digital Trigger's microcontroller – i.e., within a range of microseconds[6] (see Figure 3). This control is important, since the behavior of some smartphones depends on how long the user pushes the touchscreen key (hereinafter referred to as the "push time" in this paper):
- The synchronization signal that is sent to the LED timer can be sent either on the simulated push or on the simulated release of the capacitive trigger. Depending on the smartphones either events can be used to trigger a capture. The accuracy of this synchronization is limited by the microcontroller resolution (i.e., within a range of microseconds). In this paper, the push synchronization occurs at the beginning of the push time and the release synchronization occurs at the end of the push time (see Figure 3).

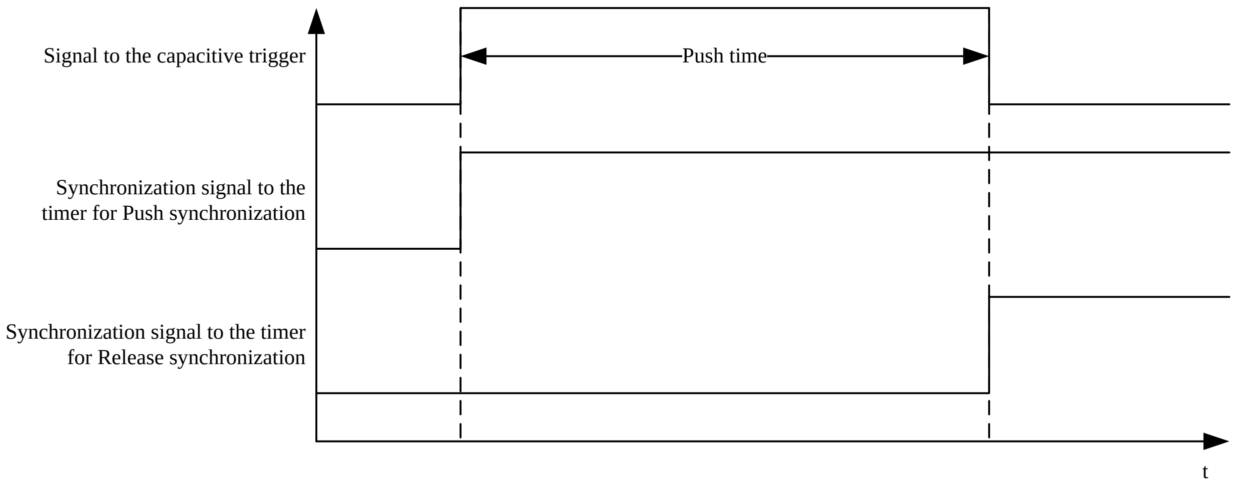

Figure 3: Representation of push duration and push time and release time synchronization.

The solution we describe in this paper has several advantages over another solution coupling a smartphone stylus with a micro switch:

- It is not possible to accurately control how long a stylus touches a screen, whereas with the DxO Touchscreen Probe and the DxO Digital Trigger, the time can be precisely controlled.
- The distance where the touchscreen detects the stylus upon its approach is unknown and depends on the device: some capacitive touchscreens can detect a finger several millimeters away. The DxO Touchscreen Probe allows for only two states, thus eliminating any ambiguity about the simulation of the finger touching the screen, which again provides for better accuracy.

The accuracy of the combination of the DxO Touchscreen Probe and the DxO Digital Trigger is better than +/- 10µs using the definition described in Annex B of the ISO standard[1]

2.3 Capture automation

The ATmega32u4 microcontroller embedded in the DxO Digital Trigger has a USB port[6] to enable using a computer to send commands to the DxO Digital Trigger, as well as to trigger a capture event while controlling its duration and its synchronization with the DxO LED Universal Timer. Since the DxO LED Universal Timer also has a USB port, the positions of the LEDs at the synchronization event can also be retrieved after the capture. This automation makes it possible to log information and to associate it with the corresponding images for a large number of captures — far above the ten individual captures recommended by the ISO standard[1]. As described in the next section, this capability can improve the test statistical accuracy for devices such as smartphones.

This automation is implemented in the DxO® Analyzer® 5.2 solution, which we used for the measurements presented here.

The hardware connections are shown in Figure 4.

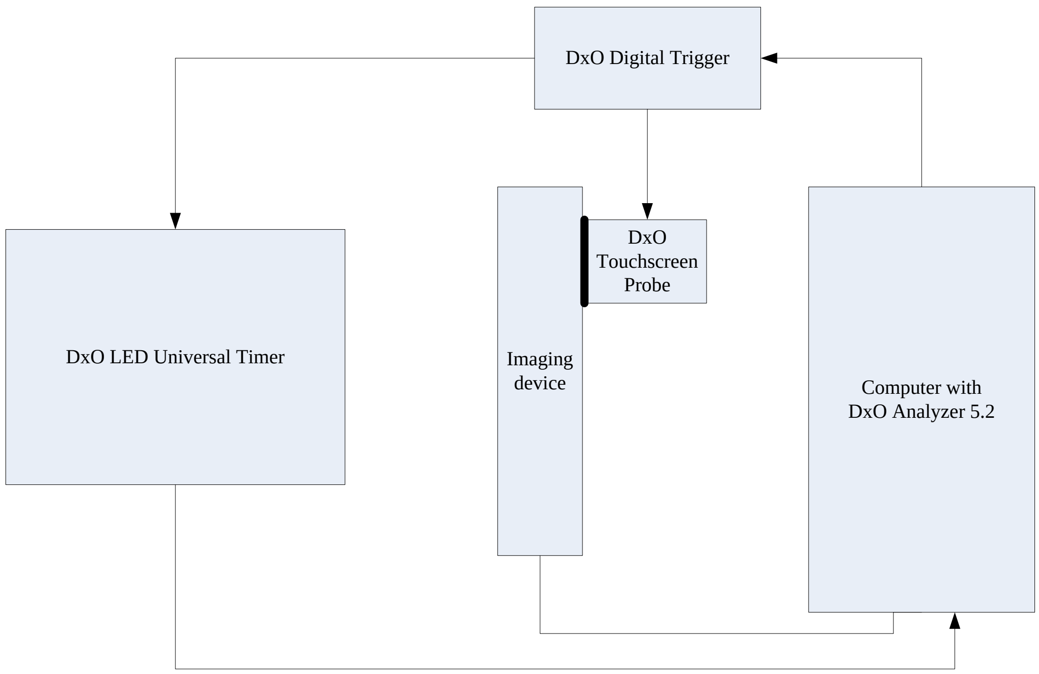

Figure 4: Connections among hardware components.

3. MEASUREMENT ALGORITHMS

As the algorithms used for measuring shooting time lag and shutter lag are the same, we use the term “time lag” in this section in its more general sense.

Measuring time lags requires detecting the first lit LEDs of each line in the captures (as described in the LED Universal Timer paper[2].) Time lag is measured by comparing the positions of the first lit LEDs of each line in a capture with those retrieved from the LED timer.

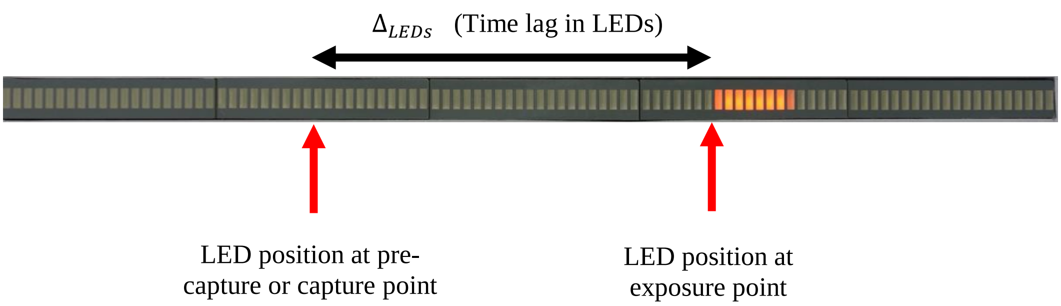

Figure 5: Calculation of the time lag from the LED positions.

As illustrated in Figure 5 above, the formula for measuring time lag (T_L) for one LED line is:

$$T_L = \Delta_{LEDs} \times \frac{Line\ period}{100}\ mod\ Line\ period$$

By using several LED lines with different periods, a time lag measurement is possible with an accuracy limited by the fastest line (i.e., maximal), within a measurement range limited by the slowest line:

- The time lag for the slowest LED line is calculated first.
- Then the time lag is calculated for a faster LED line that is compatible with the first measurement.
- The same calculations are repeated up to the fastest line.

It is worth noting that negative LED positions are possible (meaning that an image was captured before the trigger was actuated), and thus negative time lags are measurable. This is important because it extends the ISO 15781:2013 standard[1] to include imaging devices that continuously shoot and save images into a buffer, a behavior frequently found in smartphones, as the results in part 4.1 show.

The algorithm also includes a correction of bias from the rolling shutter: since not all lines in the image start their exposure at the same time, a time lag measured at the top of an image can be different from the one calculated at the bottom. This difference is equivalent to a systematic bias in the time lag measurement if not corrected. The typical value for a DSLR with a mechanical focal plan shutter, estimated from the flash sync speed, is currently about 4ms[3], which is the maximal systematic bias in the time lag measurement, depending on the position of timer in the frame. An even more reasonable bias of less than one millisecond can be achieved by following the protocol described in the ISO 15781:2013 standard [1], in which case a correction is not necessary, nor is it required by the standard.

By contrast, a typical rolling shutter value for a smartphone still capture is about 45ms[2] (thus producing an equivalent systematic bias). Even when the position of the timer in the frame is optimized, a typical systematic bias of 10ms is to be expected if rolling shutter remains uncorrected. This bias cannot be compensated by averaging several time lag measurements, and it is considered unacceptable given the potential accuracy of the system.

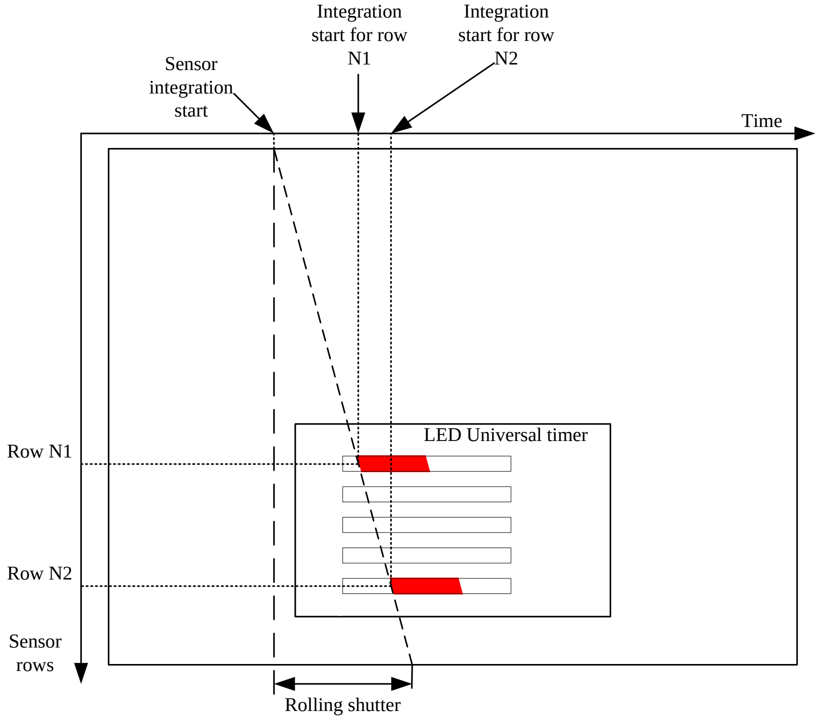

Figure 6: Correction of the bias implied by the rolling shutter.

By measuring the field position and the rolling shutter value (the latter by using the algorithm described in a separate paper[2], which involves setting and comparing pairs of LED lines with the same periods), it is possible to achieve an unbiased time lag measurement (see figure 6).

The accuracy of the measurement is limited by:

- The detection of the first lit LED on a line, which is one LED. We measured a systematic bias of about one LED.
- The detection of the timer in the frame, which is about one pixel.

These two limitations lead to a typical error of about 2ms for one single measurement, depending on the rolling shutter. By averaging multiple measurements, it is possible to attain a maximal error of about one LED on the fastest line, or one millisecond for the standard setting.

All the input parameters of this algorithm are automatically retrieved by DxO Analyzer 5.2:

- The image and the position of the LED timer in the frame, with the latter retrieved by marker detection.
- The LED line periods logged during the capture.
- The LED positions at pre-capture or at the capture point, also logged during the capture.

The algorithms we used for the measurements in this paper are part of the DxO Analyzer 5.2 solution; as they do not require manual inputs from the operator, a large sequence of images can be automatically captured and analyzed.

4. EXPERIMENTAL RESULTS

4.1 Measurements of shutter lag on the Samsung Galaxy SIII (GT-I9300)

We performed shutter lag measurements on the Samsung Galaxy SIII. Shutter lag is defined as the delay between releasing the shutter button on the screen (release synchronization) and the beginning of the acquisition. This definition is very close to the one given in the ISO standard[1]. However, as will be shown, the Samsung Galaxy SIII continuously saves images into a buffer, and is therefore excluded from the standard scope due to limitations in previous measuring devices. We set the push time at 100ms and set the exposure time by changing the chart illumination level.

Each series of measurements presented below is composed of 500 captures.

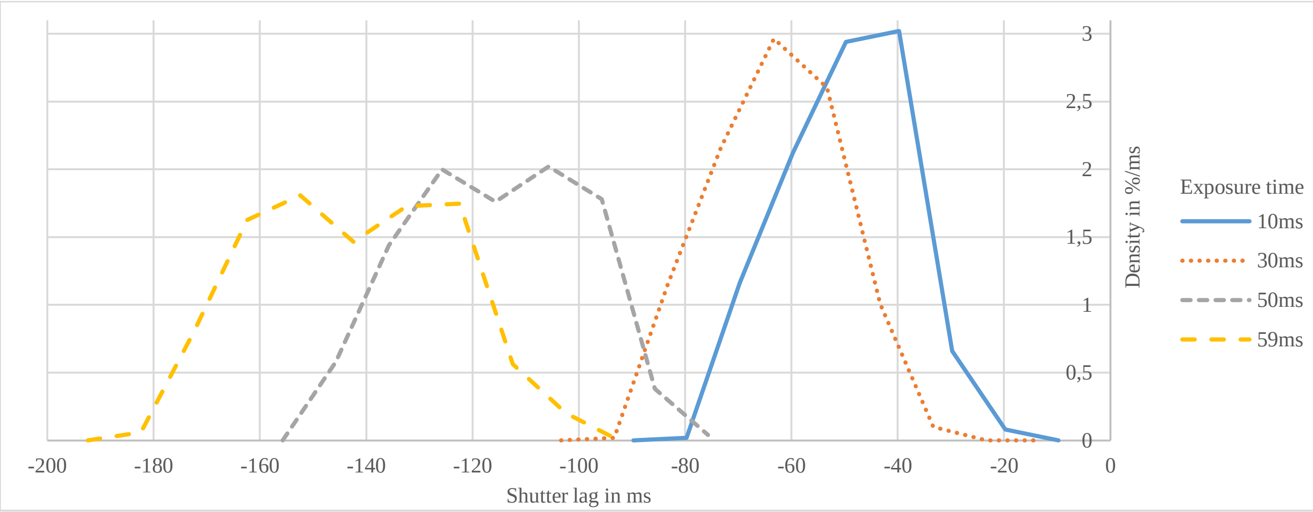

Figure 7: Distributions of shutter lag measurements for different exposure times.

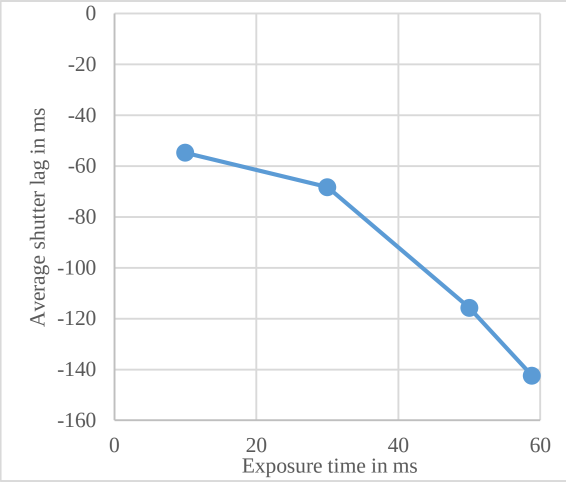

Figure 8a: Average shutter lags for different exposure times.

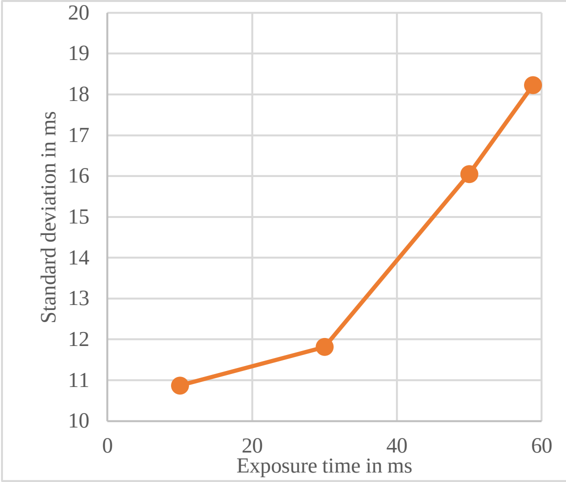

Figure 8b: Standard deviations in shutter lag measurements for different exposure times.

We can make several observations from these measurements:

- Negative shutter lags are possible with devices such as the Samsung Galaxy SIII (Figure 7 and 8a).
- A large variability in the results is visible in Figure 8b, much higher than the measurement accuracy.
- The average value and the standard deviation of the measurements are strongly correlated to the exposure time (Figures 8a and 8b).

These observations are consistent with a camera that continuously shoots images into a buffer and then processes and saves the image that is currently in the buffer when triggered:

- The image that is saved was actually shot before the trigger, and thus the shutter lag appears to be negative.
- The trigger moment can happen randomly at any time while the image that is saved is in the buffer. Further, the image stays in the buffer until the next image takes its place, which corresponds to the frame time. So the shutter lag has a variability length roughly equivalent to the frame time, leading to a large variability in the measurements.
- When the exposure time changes, the frame rate can also change, and so does the variability of the shutter lag measurements.

This type of ISP (image sensor processing) brings-up several points that are not addressed in the ISO 15781[1] standard:

- Both the shutter lag and the shooting time lag can change with the exposure time, especially with cameras whose sensors are continuously running.
- The large variability seen in shutter lag for cameras whose sensors are continuously running (as is the case for smartphones) also depends on the sensor frame rate and exposure time. So to calculate an average shutter lag with a good confidence interval, we suggest that a large number of individual measurements is necessary. For a frame time width uniform distribution and N individual measurements, the confidence interval in milliseconds is given by the formula:

$$CI = 4 \times \frac{\sigma}{\sqrt{N}} = 4 \times \frac{1000/(fps \times \sqrt{12})}{\sqrt{N}}$$

Table 1 below shows some typical numbers for individual measurements required to obtain a given confidence interval based on the above formula for a sensor running at a given frame rate:

Table 1: Required measurements for a given frame rate and a given accuracy.

	1ms	5ms	10ms	50ms
5fps	460	93	46	10
10fps	230	46	23	5
15fps	150	31	15	3
20fps	115	23	12	3
30fps	77	16	8	2

Those figures should be considered as lower limits for a given confidence interval for a camera with more complex processing. But they underscore the fact that the number of individual measurements is the limiting factor with respect to the accuracy of devices and algorithms that have little unbiased error. These figures also highlight the advantage of automated measurement from captures to calculations, which make possible measurements based on several hundred captures (assuming the corresponding accuracy is required).

Finally, these figures show that the ten individual measurements required by the ISO standard[1] might not be enough to reach an accuracy better than 10ms with a sensor acquisition at 20fps.

4.2 Comparison of shutter lag measurements among different smartphones

We performed shutter lag measurements at 1000lx on several smartphones running different operating systems, using the default camera application for each phone. (Unlike the other smartphones, the default application for the Nokia Lumia 1020, Nokia Pro Cam, requires setting the focus manually, so we therefore set the focus at the chart distance in order to measure the shutter lag.) The capture settings for each device are detailed in Table 2:

Table 2: Capture settings for shutter lag measurements.

	Push time	Synchronization	Exposure time (auto)
Samsung Galaxy SIII	100ms	Release	10ms
Apple iPhone 5	100ms	Release	8.33ms
Nokia Lumia 1020	100ms	Release	20ms
BlackBerry Z10	100ms	Release	8.13 – 8.33ms

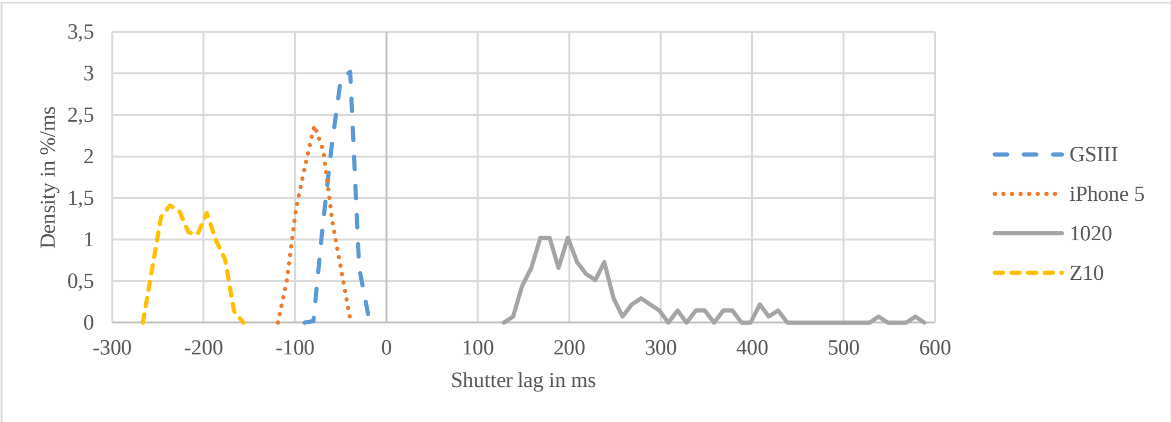

Figure 9: Shutter lag distributions for tested smartphones.

The Samsung® Galaxy SIII®, Apple® iPhone® 5 and BlackBerry® Z10® all exhibit negative shutter lags in very different ranges for similar exposure times (Figure 9). These differences can be explained by differences in hardware and software. The Nokia® Lumia 1020®, on the other hand, has a positive shutter lag and a wider distribution of measurements.

4.3 Comparison of time lag with refocus measurements for tested smartphones

The ISO standard[1] defines the shooting time lag only for imaging devices whose continuous autofocus can be disabled. However, as the continuous autofocus for most smartphones cannot be disabled, it is impossible to strictly follow the ISO protocol for measuring shooting time lags for these devices.

Even with continuous autofocus, many smartphones trigger a small refocus before capturing images. This time lag is called "time lag with refocus" in this paper.

Depending on the device, different types of events trigger a refocus (Table 3) and this may influence the results. For example, a push time above 350–400ms (the exact value was not measured) is necessary to triggers refocusing on the Samsung Galaxy SIII, thus its measurements displayed in Figure 10 include the push time. The Nokia Lumia 1020, unlike the other tested smartphones synchronizes upon release: a push does not actuate the trigger.

Table 3: Capture settings for time lag with refocus measurements.

	Push time	**Synchronization**	**Exposure time (auto)**
Samsung Galaxy SIII (1000 lx)	400ms	Push	9.9ms
Samsung Galaxy SIII (250 lx)	400ms	Push	30ms
Nokia Lumia 1020	100ms	Release	10 – 20ms
HTC 8X	100ms	Push	8.33ms

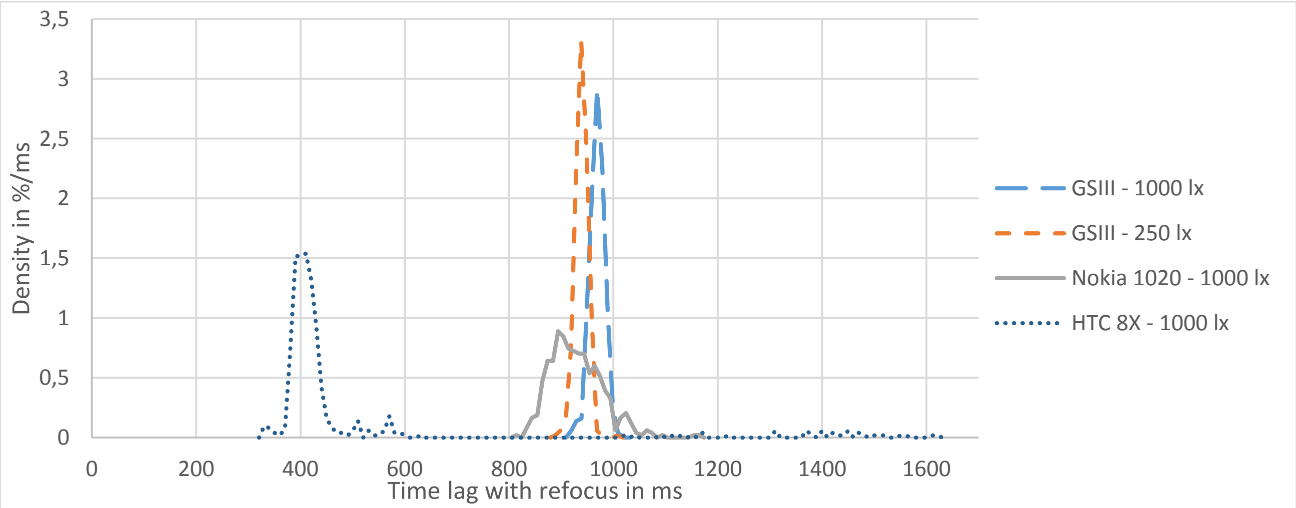

Figure 10: Statistical distributions for time lags with refocus.

These measurements show rather different behaviors:

- The Samsung Galaxy SIII's results for refocus duration are all very close.
- The Samsung Galaxy SIII is slightly faster at 250 lx than at 1000 lx, which is surprising since one would expect the performance to improve with the illuminance.
- The average time lag with refocus for the Nokia Lumia 1020 is slightly faster than for the Samsung Galaxy SIII.

- The HTC® 8X® has the fastest average speed. But its slowest time lags with refocus were the slowest among all tested devices. Furthermore, the statistical distribution of the measurements is not symmetrical, in this instance, statistical measures such as 5th and 95th percentiles are more meaningful for performance evaluation, per Table 4.

Table 4: Statistical values for time lags with refocus.

	Average	5th percentile	95th percentile
Samsung Galaxy SIII (1000 lx)	964ms	942ms	987ms
Samsung Galaxy SIII (250 lx)	929ms	918ms	986ms
Nokia Lumia 1020	929ms	860ms	1023ms
HTC 8X	458ms	313ms	1333ms

5. PROPOSITIONS FOR EXTENDING THE ISO STANDARD

The ISO 15781 standard addresses cameras equipped with a physical button for triggering a shutter, i.e., mostly DSLRs and DSCs; such cameras fall outside of the scope of this paper. However, our results lead us to make several propositions for extending this standard to smartphones and other devices that use capacitive touchscreens as a shutter button.

5.1 Continuous shooting and zero shutter lag

The ISO standard states that it does not address cameras that continuously save images into a buffer. We suggest the extension of the standard to include them using the devices and methods we presented in this paper to measure the negative time lags, that is featured on several flagship smartphones and may also be found in other types of cameras.

5.2 Actuating the timing device

Annex B of the ISO standard presents three different ways to actuate the timing device, all of which are aimed at cameras that use a physical button to actuate the shutter. But many smartphones and other devices use a capacitive touchscreen as a shutter button.

The DxO Touchscreen Probe can actuate a timing device for cameras that use a capacitive touchscreen as a shutter button, which means that the ISO standard can be extended to include methods for cameras that use a capacitive touchscreen.

5.3 Measurement conditions

The ISO standard specifies an illumination level between 500 and 5000 lx for the target, but does not require the exposure times of the images to be reported. Table D.3 of Annex D even suggests that the illumination level is not required when reporting shutter release time lag.

The measurements we presented in this paper show that the time lags can depend on sensor exposure time, especially if the sensor is continuously running (as is typical in live view).

The ISO standard should be extended to require more specific measurement conditions – i.e., the exposure time and/or the illumination level should be systematically reported for shooting time lag and shutter release time lag.

5.4 Measurement accuracy

The ISO standard requires ten individual measurements for a time lag measurement. The reported value is the average of these measurements and its accuracy is meant to be the accuracy of the measurement method.

However, measurements in this paper show that there can be non-negligible variations among each individual measurement included in a typical shutter lag measurement. This means that the accuracy of the average time lag is a combination of the measurement method accuracy and the number of individual measurements. As presented in

Table 1, the accuracy achievable using ten individual measurements is at best 10ms for typical sensor frame rates.

The ISO standard should take the number of individual measurements into account: time lags based on ten individual measurements cannot be reported with an accuracy better than 10ms; time lag reports based on more than ten individual measurements should take into account any experimental variations in accuracy measurements in addition to the measurement method accuracy.

5.5 Additional statistical values

Whereas the ISO standard requires reporting only the average time lag, measurements in this paper show that other statistics can be meaningful, in particular the standard deviation and the 5th and 95th percentiles. The ISO standard should incorporate such statistics when enough individual measurements are performed (e.g., refer to Table 1 above).

6. CONCLUSION AND PERSPECTIVES

We have presented in this paper a novel device, the DxO Touchscreen Probe, which can simulate a finger touching a capacitive touchscreen. Coupled with a DxO LED Universal Timer, it allows automatic measurement of time lags for smartphones, from capture to calculation. These devices together achieve a very high synchronization accuracy, better than 10µs, and an overall time lag measurement accuracy of 2ms for one image.

We have demonstrated that negative time lags are also measurable, and that this ability can extend the ISO standard to include devices that continuously save images into a buffer. As the measurements presented in this paper show, the accuracy of the average time lag is mostly limited by the variability of the measured imaging devices themselves, and therefore by the number of individual measurements and the settings of the DxO LED Universal Timer. Because of the automation that they facilitate, the devices and methods presented in this paper generate accurate statistics based on a large number of captures.

The measurements we presented highlight the strong impact of exposure time on shutter lag and shooting time lag; the ISO standard[1], by contrast, does not recommend any particular exposure setting during testing. Furthermore, the measurements illustrate that an intrinsic correlation exists between the variability in time lags and sensor and ISP parameters. Finally, we pointed out that using several different statistical indicators (i.e, percentiles and standard deviation) can be a useful and relevant way to evaluate the performance of a system.

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