Going Mobile: Evaluating Smartphone Capture for Collections

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Abstract

There are now institutional guidelines that define several image quality measures, and set performance requirements for image capture. Based on these, it is now common practice to monitor image acquisition performance for digital collections. Important image characteristics include the influence of lighting, lens focus, and several aspects of general imaging practice. Normally these efforts are applied to digital scanners and professional cameras. As cameras in mobile-telephone cameras have improved, however, these are sometimes used as convenient document scanners. Addressing the evaluation of image resolution and optical distortion, we describe how imaging performance can be evaluated against US federal (FADGI) and Matamorfoze guidelines. Results from our smartphone test indicate that, for the attributes tested, the unit would meet at least three-star performance for up to A4 document scanning, and possibly better. We show that it is possible to identify the domain of acquisition conditions under which these cameras can meet the requirements for cultural heritage imaging.

Introduction

Monitoring imaging performance is often performed for image acquisition for archives, libraries and museums.[1] Several methods have been adopted in guidelines,[2,3] with the aim of reducing variation that can occur, e.g., from day-to-day during an extended project. Normally these efforts are applied to digital scanners and professional cameras. As cameras in smartphones have improved, however, these may be used as convenient scanners. Figure 1 shows an example in a small copy-stand.

Figure 1: Mobile phone camera used in small copy-stand arrangement

In Fig. 1 we see a small tripod and a remote camera trigger switch. Also shown are reference test objects used to evaluate both the image color-encoding and resolution performance. Since the test object features are of known size, we can determine the image (pixel) sampling of the object. For example, the image captured from our test set-up was sampled at 672 pixels/inch (PPI) in the object-plane.

Before describing the imaging performance guidelines and evaluation methods that we can apply to mobile phone cameras, it is helpful to consider several available smartphone cameras. Table 1 lists the image (sampling) size in mega-pixels available from several current advanced smartphones.[4] We note a fairly wide range in image sizes. For our applications, we would normally be using the main, high-resolution camera. As we will see, from the image pixel size (number), we can match this with a maximum object size, based on institutional guidelines.

Table 1: Camera image (sampling) sizes for several mobile telephone cameras in megapixels (Mp), adapted from ref. 4

	Main camera, Mp	Front camera, Mp	Optical stabilization
Apple iPhone 6S	12	5	No
Apple iPhone 6S Plus	12	5	Yes
Google Nexus 5X	12.3	8	No
Google Nexus 6P	12.3	8	No
HTC One M9	20	4	No
Motorola Moto X Force	21	5	No
LG G4	16	8	Yes
OnePlus 2	13	5	Yes
Samsung Galaxy S6 Edge	16	5	Yes
Sony Xperia Z5	23	5	No

Compact lens design, such as for a mobile hand-set, results in a balance between image sharpness, depth-of-field, and optical distortion. So for our discussion we will focus on two imaging performance characteristics that are influenced by the (small) size of the image-capturing optical module; the Spatial Frequency Response (SFR)[5,6] and optical distortion.

Imaging Guidelines and Standards

The past few years have seen the formation of the US Federal Agencies Digitization Guidelines Initiative (FADGI), led by the US Library of Congress. The guidelines apply several imaging performance evaluation methods that were previously developed for, e.g., digital cameras, scanners and printers. The document established several increasing levels of imaging performance. These are described in terms of from one- to four-star ratings. The

reason to have several imaging performance levels is that not all collections (e.g., newspapers vs. photographic prints) have the same imaging requirements.

The SFR [5, 6] is a measure of a camera or scanner's ability to capture and record object detail in the digital image. SFR performance is influenced by the capture optics and detector. The sampling efficiency (SE) [7] is a summary measure that combines SFR performance with the image pixel sampling of the detector. It is computed as the ratio of the spatial frequency of the 10% SFR value to the maximum frequency. The recently posted [2] version of the FADGI still imaging guidelines includes a proposed change in the sampling efficiency to 0.85 from the original 0.90, for a four-star rating.

Other guidelines for cultural heritage imaging use these measures and techniques. For example, the Matamorfoze Guidelines[3] adopt the 85% sampling efficiency criterion based on the above 10% SFR value. In addition a 50% SFR measure, referred to as MTF_{50}, is used.

Relating image pixels, guidelines and object size

For the various types of collection material, specific imaging practice is adopted within the community. A basic parameter for both camera and scanner systems is the image sampling. This is often expressed as pixels/inch (PPI), or pixels/cm on the object. Table 2 reproduces the minimum image sampling from Ref. 2. Image sampling is sometimes called 'sampling resolution' or just 'resolution', but these terms can be confusing. The required sampling also varies with the image quality level established for any particular project, expressed from one to four stars (in increasing high quality). Note that for the broad Artwork category, the digital image size in pixels is specified, rather than sampling, due to the wide range of object size encountered.

If we know the pixel dimensions of an image file delivered by our camera, and the required sampling on the object, we can compute the maximum allowable object size. Consider the Apple iPhone 6S with its 12 Mp image size. If we assume a common 3:4 aspect ratio (image height**:**width), then we can expect a 3000 x 4000 pixel image. If we were to meet a FADGI three-star rating for book scanning, we see from Table 2 that we need a minimum sampling of 300 PPI. In this case the longer image dimension spans,

$$w = \frac{4000 \; pixels}{300 \; pixels/inch} = 13.3 \; inches \; (33.9 \; cm)$$

which would accommodate an A4 size document.

Image sampling specifies how *much* image data is collected, but not the quality of the data. Image sampling, therefore, is a necessary but not sufficient condition for the capture of image detail. As discussed above, the imaging guidelines also specify how *well* the image detail is captured. This is expressed in terms of a computed spatial frequency response (SFR) measure.

Figure 2 shows computed SFR characteristics that would meet the four-star ratings, for a 90% and 85% sampling efficiency. The form of the computed SFR is a gaussian function. In this example, we chose the 600 PPI sampling required for 4-star imaging of photographic prints (Table 2).

The 600 PPI or sampling pitch of 0.0423 mm. determines the maximum (half-sampling) frequency of 11.9 cy/mm. A Gaussian

vector was computed as the effective image capture point-spread function. The width parameter of the Gaussian function (its standard deviation) was adjusted to achieve the required sampling efficiency, based on magnitude of the Discrete Fourier Transform (DFT), which in this case is the SFR.

Table 2: Minimum image sampling on the object from FADGI Guidelines for various collections, ref. 2.

|	Image sampling, pixels/inch			
Performance Level	1 star	2 star	3 star	4 star
Spec. col.* book	-	300	300	400
Book	150	300	300	400
Spec. col.* document	-	300	300	400
Document	150	300	300	400
Maps, drawings, Oversized	150	300	300	300
Photographic print	100	200	400	600
Still film up to 4x5	1000	2000	3000	4000
Still film > 4x5	500	1000	1500	2000
X-ray film	300	400	500	500
Microfilm	300	300	300	400
	Pixels in long dimension			
Artwork	3000	5000	10000	12000

*Special collections
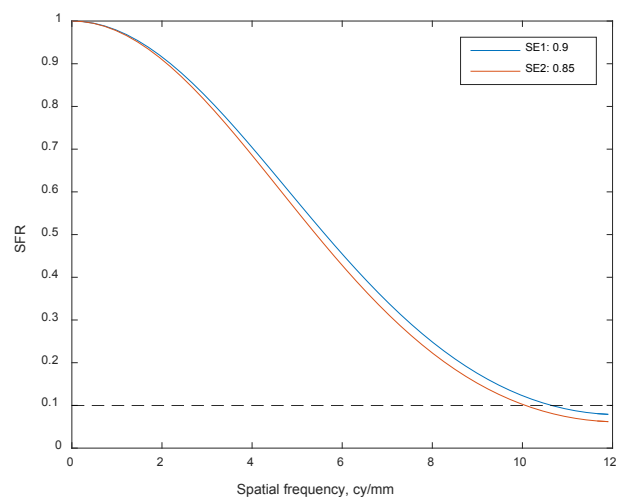
Figure 2: *Two computed gaussian SFR characteristics with sampling efficiency of 0.90 and 0.85*

Table 3 summarizes the minimum SFR-based sampling efficiency called for in the FADGI Guidelines. The corresponding value for Matamorfoze is 85%.

Table 3: Minimum SFR Sampling Efficiency from FADGI Guidelines for various collection materials, ref. 2.

	SFR Sampling Efficiency, %			
Performance Level	1 star	2 star	3 star	4 star
Special collections book	-	70	80	85*
All other collection material categories	60	70	80	85*

*The original four-star requirement was 90%. A 85% value is under consideration.

Optical Distortion

One important area of imaging that has yet to be included in the FADGI guidelines is optical distortion. However, we can call upon the recent ISO 17850 standard for a geometric distortion measurement. In addition, ISO 19084 addresses the wavelength (color) dependent nature of optical distortion. The term *distortion* is often used in different ways, but we are only addressing that resulting in object rectangles not being captured as rectangles, e.g., due to barrel, pin-cushion or similar aberrations. We do not include simple *x,y* sampling differences, tone-contrast errors, or sampling artifacts in our discussion of *distortion*.

The ISO 17850 standard[8] uses images of a test target composed of a regular array of dark dots, as shown in Fig. 3. This image was captured by an Apple iPhone.
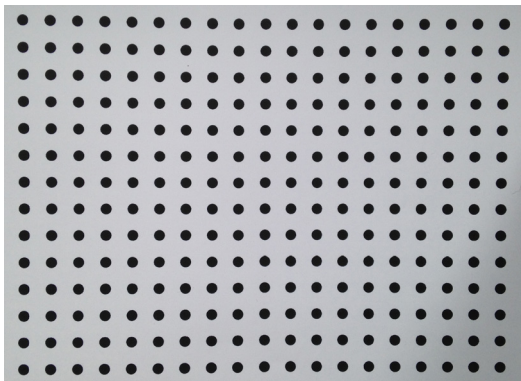

Figure 3: *Dot pattern used to geometric distortion as per ISO 17850 standard*

The ISO Geometric distortion evaluation standard calls for automatically locating the centers of each dark dot in the image. These pixel coordinates are then compared with the corresponding (known) regularly-spaced target locations. The difference in each location is computed as a % distortion.

A related imaging standard is ISO 19084, for chromatic displacement measurement. The displacement is between the red, green and blue image information in the image, usually due to optical aberrations. The optical properties of any lens system are influenced by the wavelength of the light passing through. Although optical design mitigates this 'error', it causes the red, green and blue components of the image to fall on different (shifted) locations of the image sensor.

Results

SFR, Sharpening and sampling

We now apply the above imaging performance measures to the mobile phone based copy stand setup shown in Fig. 1. using an Apple iPhone 5C unit. Test images were acquired for two test charts; one included several high-quality edges for SFR analysis, and the other is shown in Fig. 3, for optical distortion.

Following good photographic practice was helped by using the built-in Level software tool, part of the Compass utility. We used this to ensure that the iPhone unit and test target were both level (on parallel planes). This reduced keystone effects in the test images, which would influence both SFR and optical distortion results.

Normally the acquired images from mobile-phone cameras are encoded in a compressed, JPEG image format. This includes spatial processing and may have an influence on the measured imaging performance. However, most cultural heritage imaging, certainly for master files, calls for uncompressed image acquisition.[†] Although we tested the camera for both lossy compressed and uncompressed conditions, we only present the uncompressed results in this paper.

The 8 megapixel (MP) test image would satisfy the FADGI 3-star and 4-star sampling requirements for A4 and A5 sized documents, respectively. Test images were captured as shown in Fig.1, with an exposure time of 1/140 sec. and lens f/2.4. Using third-party software, the image was captured in an uncompressed TIFF format. The results for the SFR analysis for a vertical edge feature are shown in Fig. 4.
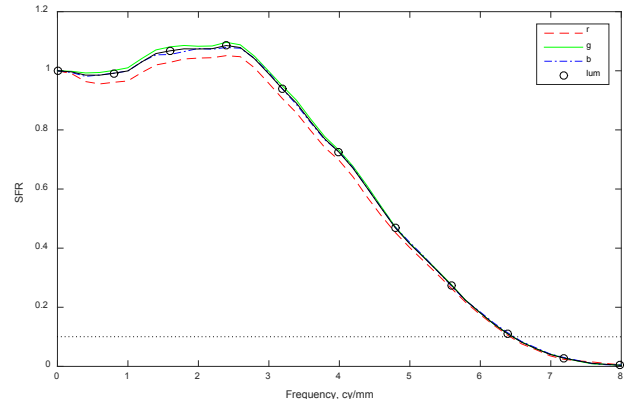

Figure 4: *Edge-SFR results for mobile phone camera with uncompressed image capture*

From the observed rise in SFR values between 1-3 cy/mm, we conclude that digital image sharpening is being applied. This is to be expected, and the FADGI Guidelines specify a maximum amount of image sharpening, as indicated by the maximum of the measured SFR curve. From Fig. 4 the maximum value is 1.1 which

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[†] Although there is interest in using JPEG$_{2000}$ image compression for cultural heritage projects, discussions of whether and when this should be restricted to lossless settings are ongoing.

would meet the three-star performance level. We also note that the SFR results are consistent for all image color-channels.

It is possible to identify the image sampling range for which our test system would meet the SFR imaging resolution guidelines. From fig. 4, we see that the 10% frequency is 6.4 cy/mm. So for a sampling efficiency of 90%, this system could be operated with a half-sampling frequency of

$$6.4/0.9 = 7.1 \text{ cy/mm} \qquad (1)$$

This implies a sampling interval of 0.141 mm, or 357 PPI. So taken together with the above sharpening criterion, these results indicate a three-star FADGI performance was achieved for all reflective material except photographic prints, which require 400 PPI sampling. It is also likely that, with some adjustment of the digital image sharpening, that this system could pass a four-star rating for an adjusted (object) working distance.

Distortion

Based on the captured test target shown in Fig.3, the ISO 17850 analysis method finds the location of the dot-centers automatically. The distance between the neighboring locations near the center of the image is then computed as a reference distance (i.e. with minimal distortion). The set of distances of the detected locations from their corresponding (regularly spaced) ideal locations can be displayed at a quiver plot. This is shown in Fig. 5, computed from the test image of Fig. 3. Each of the arrows, from reference to image, is plotted as 150% of the actual detected distance to make them more visible.
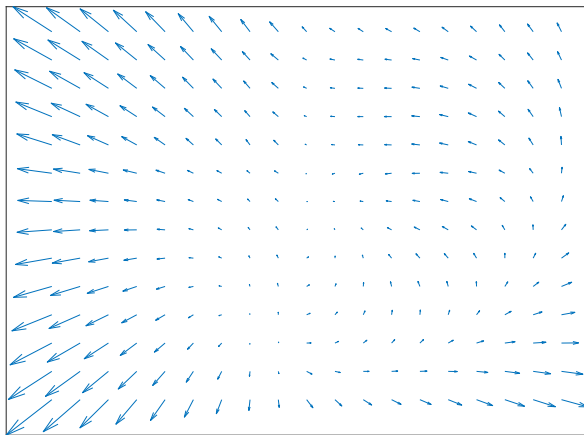

Figure 5: Quiver plot representing measured geometric distortion where each arrow (distance) length is drawn as 150%.

Note that the distortion pattern is not symmetrical about the center. This is a result of the actual camera performance, but may also be influenced by residual misalignment of the camera over the center of the target. This could be reduced by realignment of the camera so it is centered and parallel with the intended object plane.

The same set of data can be plotted as a % distortion measure, called for in the standard. This is shown as a function of image distance from the center, labelled actual image height. The range in measured geometric distortion value is due to the asymmetric

nature of the measured distortion. As we would expect, the distortion is greatest near the margins of the image-field.
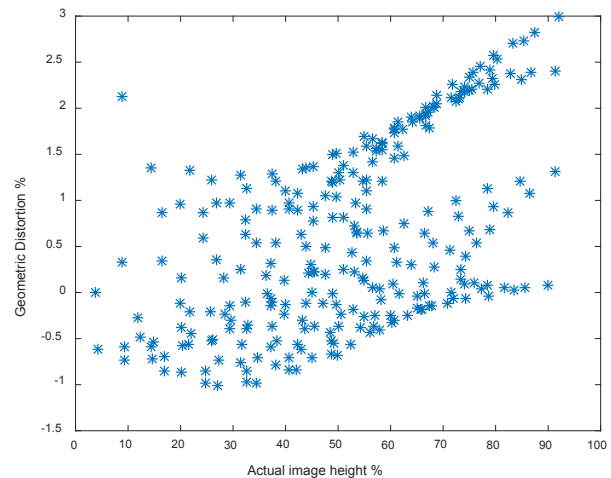

Figure 6: Measures geometric distortion plotted as a a fractional distance between detected location and ideal location

The above geometrical distortion results are based on a single computed luminance image (or sometimes the green record). However, since we have a three-channel color image, we can use the same dot detection method for each of the *r, g, b* color records. In this case we then compute the two sets of differences; *r-g*, and *b-g*. Results for the camera under test are shown in Fig.7. Here we see small detected color-shifts of less than a pixel. This is consistent with the visual inspection of the test image, where very little color-fringing was visible on the edges of the dots.
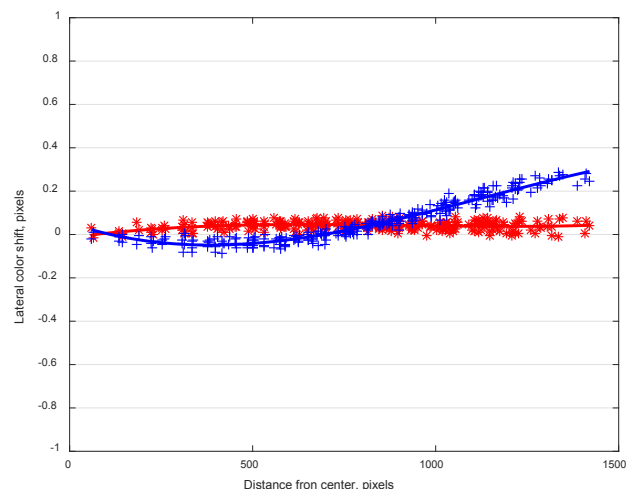

Figure 7: Results of lateral color displacement measurement

Conclusions

While smartphone cameras are not designed with cultural heritage imaging in mind, recent technical improvements and convenience make them candidates, at least for small projects. In this paper, we have discussed their use in the context of

institutional imaging performance guidelines. Rather than answer the question of whether current smartphone camera performance is acceptable, we indicate how to identify the imaging domain (collection material, size, etc.) over which a camera can provide acceptable performance. We have considered relationships between; image (megapixel) size, object sampling and imaging resolution. We have also introduced ISO standard-based methods to evaluate and specify two forms of geometrical distortion, important for cameras with small optical elements.

Our evaluation of a particular smartphone camera indicated, based the attributes tested, that it would satisfy at least a three-star FADGI performance level. We also conclude that, with some adjustment of the digital image sharpening and good imaging practice, that the current generation of smartphone cameras can likely achieve a four-star rating. Improvements in performance can be expected by careful adjustment of camera and object alignment. In addition we suggest considering; any image compression and digital sharpening settings, a remote shutter release, and use of tap-to-focus feature, if provided.

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Author Biography

Peter Burns is a consultant supporting digital imaging system and service development, and related intellectual property efforts. Previously he worked for Carestream Health, Eastman Kodak and Xerox Corp. He is a frequent conference speaker, and teaches courses on these subjects.

Don Williams is founder of Image Science Associates, a digital imaging consulting and software group. Their work focuses on quantitative performance metrics for digital capture imaging devices, and imaging fidelity issues for the cultural heritage community. He has taught short courses for many years, contributes to several imaging standards activities, and is a member of the Advisory Board for the interagency US Federal Agencies Digitization Guidelines Initiative, FADGI.