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Preparing for the Image Literate Decade

Don Williams, Image Science Associates, and Peter D. Burns, Carestream Health, Inc, Rochester NY USA

Abstract

The utility of digital over traditional imaging methods in terms of data delivery, access, and manipulation are undeniable and well recognized. Data literacy in such digital matters is well established. What is not yet developed, but slowly emerging, is an accompanying image literacy; the ability to measure, test, and visually recognize good images from bad ones, based on project requirements Leading practitioners are realizing that there are significant additional responsibilities that come with the adoption of digital imaging. Not the least of these is for the control of the performance variability that comes with the freedom of system component selection.

Currently several initiatives being developed by national libraries, institutions and funding organizations will directly influence clients' expectations. We describe how US and European initiatives will influence the requirements for both imaging performance, and how this will be managed in digital conversion projects. We interpret these developments in terms of the necessary tools and methods for quantifying and maintaining performance consistency. Rather than presenting a list of requirements for, e.g., image effective resolution, distortion, tone-and color reproduction, we present a way to establish an imaging quality-assurance program. The elements of a successful program should include; establishing of performance goals, efficient test plans and performance tracking tools, and interpretation for corrective action.

Introduction

In the last few years, several initiatives aimed at improving both the efficiency and quality of imaging practice for digital conversion projects have been developed. In this paper we report on how progress in this area can be understood in the context of corresponding quality assurance efforts in manufacturing industries. We will also see how national and international imaging practice guidelines are having an influence on the expectations of both service providers and cultural institutions.

The adoption of digital imaging technologies for content delivery, access, and manipulation is well-recognized, and almost universal. What is not always recognized is that the very choices and variety of system hardware and software components can lead to variable quality of the imaging results. A good working knowledge of such matters, what we call *image literacy*, is needed by both institutions and internal or external imaging service providers.

What are being developed are techniques and tools which facilitate the measurement, testing, and visual evaluations to identify of areas for improvement of digital imaging content. As tools and educational resources become more available, leading practitioners are realizing that there are significant additional responsibilities that come with the adoption of digital imaging. Not the least of these is to control the increased performance variability that comes along with the freedom to choose between hardware, software and image manipulation components of the acquisition system.

Unlike the world of analog imaging, where one could confidently rely on the history-rich reputation of a few manufacturers for imaging performance integrity and consistency, today's digital imaging landscape offers fewer assurances. Fortunately, there is a gradual awakening to literate imaging through international standards, education, and appropriately prepared imaging specifications. Manufacturers and service providers should expect to be increasingly challenged by clients with respect to imaging performance and consistency.

We adapt a Scottish definition[1] of literacy (and Numeracy) as it applies to digital imaging;

> **Image literacy** (n): The ability to read, interpret and use generally accepted imaging results, to handle the corresponding performance information, to express ideas and opinions, to make decisions and solve related problems.

This definition is especially appropriate because it articulates a move away from the colloquial, and frequently confusing, imaging terms and practices towards standardized imaging measurement protocols. They are easily communicated and facilitate sound, economical and appropriate image digitizing decisions, by the numbers.

Such literacy has been advocated in the past by several authors. Lessons on digital capture *specsmanship* were presented by Williams 2003 [2]. This was followed by more general policy papers by Stelmach[3] and Murray, [4] who made a case for quality control and quality assurance in digitizing workflows. Puglia[5] *et al.* provided guidelines in 2004, consistent with the above developments. Two Dutch initiatives reduce several of these ideas to practice in imaging requirements, not just guidelines, in the *Metamorfoze* [6] effort, and for projects for the Nationaal Archief, Sound and Vision, and Film Museum Institutes. A rational imaging understanding fueled by sound technical backing is beginning to prevail and will likely continue to emerge over the next decade.

Image literacy will be more widely enabled on a number of fronts. It will be motivated by a need for simple and consistent imaging where collection content and expected image usage will be matched to technical requirements for image acquisition. The enablement will be provided through 1) educational and training resources, 2) efficient measurement and quality control tools, and 3) a willingness to apply these diligently.

While some service providers and device manufacturers may view the added requirements as a burden, the more competent among them will welcome such literacy as a way to distinguish their services from the less worthy. Content providers too should be aware that using the knowledge that this approach provides will allow them to better understand the prices that service providers and device manufacturers quote for demanding imaging tasks.

Organizing the Idioms

In our proposed definition of literacy, the reading and writing of imaging is fundamental. Having the advantage of offering classes and training on digital imaging performance, we have concluded that eliminating ambiguous communication is the first and most important step in creating solid image literacy. For instance, confusion continues to exist between image sampling and optical resolution. Dynamic range is still specified in terms of the number of encoding bits/pixel. And there is wide confusion around the unusual forms of image 'noise' that manifest themselves in digital imaging.

<table>
<tr><td>Foundation Attribute</td><td colspan="11">Signal</td></tr>
<tr><td>Primary Metrics</td><td colspan="5">OECF (Opto-Electronic Conversion Function)</td><td colspan="6">SFR (Spatial Frequency Response)</td></tr>
<tr><td>Secondary Metrics</td><td>Linearity</td><td>Sensitivity,</td><td>Tone, Exposure</td><td>White Balance/ Neutrality</td><td>Color Rendering or Encoding Accuracy</td><td>Sampling Rate</td><td>Resolution, sampling efficiency</td><td>Sharpening</td><td>Acutance</td><td>Flare</td><td>Depth of Focus</td></tr>
</table>

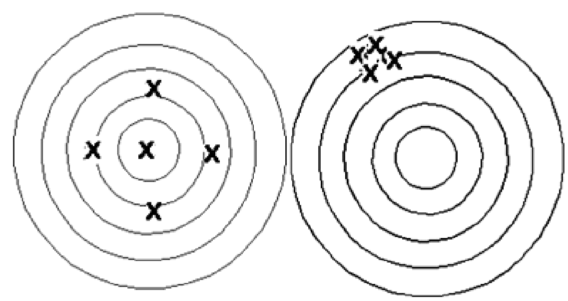
Fig.1: Portion of Imaging Performance Framework

Just as the Swedish botanist, Carolus Linnaeus, proposed a botanical taxonomy to organize plant names, we provide one for imaging performance evaluation. The purpose is more than just a nomenclature translator, or glossary. It is a hierarchical framework for understanding the landscape of digital capture performance and its related standards, be they sanctioned or *de facto*. The fundamental classes are Signal and Noise. For each of these we identify primary imaging performance measures. These primary measures for signal capture attributes are the Opto-Electronic Conversion Function (OECF) and Spatial Frequency Response (SFR). Similarly, noise is classified as a distortion, being either spatial or radiometric in nature. From these four divisions more commonly used terms such as resolution, gamma, fixed pattern noise, or color misregistration are related. A graphical description of a portion of this framework is provided in Fig. 1. A full description of the taxonomy can be found in a companion paper.[7]

The objective of the framework is to indicate the relationship between common imaging performance measures and methods. We do this with an eye to the development of practical, economical, standard approaches that can simplify communication and facilitate negotiation in this area. The framework also associates true performance metric names with the vernacular surrogates. For instance, qualitative terms like soft, blurred, aberration or focus are all colloquial terms used for describing image resolution and the appearance of sharpness. Similarly, haloing, unsharp masking, and edge enhancement are all generic terms for describing sharpening operations. Both can be understood and evaluated using a standard spatial frequency response (SFR) evaluation as indicated in Fig. 1.

Accuracy, Precision and Calibration

The control and improvement of digital imaging content requires that we observe and understand the important characteristics of our image acquisition process. Adopting the terminology of statistics, we can think of a measurement as an estimate of an underlying parameter. For example, when we compute the 'average value' (sample mean) from several observations, we are estimating the true mean value of the process being observed. A measurement whose observations are centered on the true value, as in Fig. 2a, are said to be *accurate*. However, if the observed data are closely grouped, as in Fig. 2b, the measurement is said be *precise*.



a. *b.*

Figure 2: Two types of measurement variability; a. indicates high accuracy but low precision, b shows low accuracy but high precision

Naturally, we would prefer having measurements of imaging performance with high accuracy and precision. Given the choice of either situation *a* or *b* of Fig. 2, however, selection *b.* is often preferable if it implies that the error in the average measurement is predictable. A predictable error, or bias, can often be corrected as part of a measurement and analysis system. This correction is a form of *calibration.* An analysis step that seeks to improve measurement accuracy is a form of calibration.

The concept of a correctable bias can also be applied directly to the content of digital images. In one sense, a digital image is itself is a form of measurement of an object or documents. The physical characteristics being 'measured' by the discrete pixel values can be expressed in terms of the reflected or transmitted light, as selected by an image detector sensitive to particular wavelengths of light. When we observe (measure) that a digital image is 'inaccurate', we often attempt to remove bias in the data, by image editing.

The experienced practitioner of imaging performance evaluation is aware that there are limits to calibration. Just as in image editing, the data may also have low precision, and large calibration corrections can amplify normally acceptable random errors. The image-literate project manager knows enough to ask about measurement accuracy, precision and their sources.

Critical and Sufficient Imaging Criteria

A component of image literacy is knowledge of what level of imaging performance is sufficient for any particular collection content. Too often, out of naiveté or simple ignorance, digitizing requirements are over-specified. Except for the most demanding spatial detail, true 600 dpi scanning is rarely required for most reflection work. Yet this requirement is often rubber-stamped into digitizing requirements simply because it is a safe, albeit expensive, and incomplete choice. Another example can be cited in the digitizing of black and white (silver-halide) film negatives. There is a natural tendency to demand high dynamic range scanning with such content. Pilot studies have shown though that only a small portion of film samples in this category actually contain densities that require high dynamic range scanning. As we gain experience with such scenarios more rational and moderated digitization guidelines can be expected for selected content.

On the other hand, more critical specifications will emerge for other content. For example, in the digitization of large objects in A1-A00 format sizes, uniform imaging behavior across the entire field of view is usually required. Tighter imaging specifications around color misregistration, stitching artifacts, lighting uniformity, and resolution uniformity will undoubtedly apply. Device manufacturers and service providers should be aware of this.

It is natural to think of imaging performance behavior in terms of its boundaries. For instance, in dynamic range and color gamut specifications greater boundaries are typically desired. If a limited *sRGB* gamut is good, then a wider *AdobeRGB* must be better. If 1500 dpi scanning of black and white film negatives is good then 2500 dpi must be better. This "more is better" thinking can actually detract from high fidelity imaging of certain objects. In faithfully digitizing 19th century photographs the real challenge is to sufficiently capture the subtle and finely incremented tones and near neutral colors. Wide color-gamuts and large dynamic ranges may actually detract from such a goal. It is logical, in fact, to desire a minimized color gamut so that the available digital count levels may be efficiently assigned just to those limited colors in the collection content. An insufficient color gamut in this example is not the problem.

Another example: there is increasing evidence that digitizing some B&W film negative collections at too high a resolution can actually detract from the image quality of the final image. This is possible. The film grain can interact with high quality scanners to create the equivalent of random-moiré fluctuations in the final image. The effect is unexpectedly high noise in the final image that is neither a result of the film nor the scanner alone but in their interaction.

Also, expect the regulation of sharpening operations. Sharpening can not only be detected but quantified by means of the Spatial Frequency Response (SFR). Such specifications will likely limit the extent to which sharpening can be applied so that un-natural over sharpening will not occur and maximum re-purposing is maintained. These type of usage- or content driven specifications, and digitizing guidelines that go with them are emerging through collaborations like the Federal Agencies Digitization Guideline Initiative.[8]

Device Performance Database

Consistent with our definition, literacy requires knowledge from which good decisions can be made and problems solved. Having a reliable source of independently generated information, on which users can make their own decisions, provides the fuel for literacy improvement. Having an imaging performance database of cameras and scanners is one way of accomplishing this. The authors are often asked to provide comparative imaging performance data of scanners and digital cameras. There are typically two reasons for these requests. One is for purchase decisions. The other is for comparison to either a benchmark capability of the scanner provided by the manufacturer or for performance comparison with similar scanner models used throughout the community.

There is a consensus in the cultural heritage imaging community that such a database would be very helpful. A number of device manufactures have, in fact, expressed an interest in participating in populating this resource. Once a critical mass of participants and devices are identified it is very likely that this will occur. Evaluations and test plans will likely be accomplished through a independent imaging performance service providers.

Elements of a Successful Quality Assurance Program

Once the content and objectives of a digital conversion effort have been established, and measurement variability understood, imaging performance goals can be established. These are often done using standardized physical test objects (targets) and dedicated analysis software methods. Some of these can be adapted from those used in the professional photography and printing industries.

After one has identified the right characteristics to measure, the next step is to understand and measure normal or in-control variability. This can then be differentiated from performance that requires corrective action. Both control limits, and testing plans can then be tailored to particular projects, based on observed performance.

The selection of performance tracking tools often follows directly from the standard imaging performance methods adopted in imaging component and content requirement selection. In some cases, however, simplified summary measures can be used for routine quality assurance evaluation. Consider the well-established imaging resolution measurement for digital cameras and scanners, based on the analysis of edge features.[9] The resultant spatial frequency response (SFR) is commonly used to support both design and evaluation activities. To simplify routine performance measurement, a summary measure, such as a limiting resolution (or effective resolution), based on a threshold value such as a 10% response can be used. This single value facilitates the use of this standard measurement to control charts. When abnormal values are observed, the corresponding SFR data can then be retrieved and used to identify corrective action.

As an example of the use of the limiting resolution measure, consider the results of a set of SFR evaluations for a digital copy-stand conducted over eleven consecutive days, as shown in Fig. 3.

A test target was included at the edge of the imaging field for each test image. The actual image sampling on the test object, as inferred from target features was then compared with the corresponding tagged values in the images files. Consistent results were observed until the seventh day, attributable to changes in the lens focal position. The analysis was automated and simple, when enabled by the inclusion of the test target.

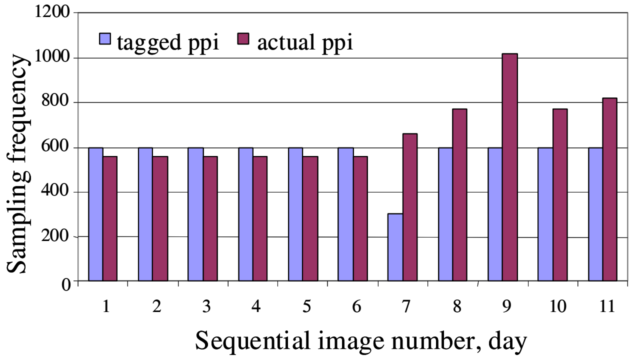


Figure 3: Results for tracking of tagged (labeled) and actual image sampling, in pixels per inch, over eleven days

The same set of test data were used to measure the SFR and limiting resolution, based on a 10% response. From Fig. 4 we see a straightforward comparison of image sampling (resolution) with the capture of image detail, imaging or optical resolution. The ratio of these values is taken as a measure of sampling efficiency, is seen to be particularly low in days eight and eleven.

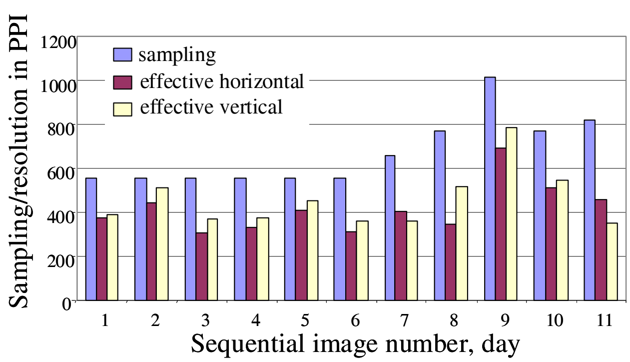


Figure 4: Corresponding sampling and effective sampling basd on a 10% SFR criterion

Conclusions

Those responsible for the development of digital imaging content for libraries and museums will be well-served by acquiring a familiarity with the basic technology, characteristics and evaluation method of digital imaging. This image literacy will be facilitated by emerging standards, national and international initiatives, and the development of automated testing and analysis techniques. These will be useful not only for system component selection, but as parts of part of imaging performance quality assurance programs. The elements of a successful QA program should include; establishing of performance goals, efficient test plans and performance tracking tools, and interpretation for corrective action.

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Author Biographies

Don Williams is a consultant on digital image fidelity for the cultural heritage sector, and previously worked at Eastman Kodak Company for 25 yrs. He is currently contributing on imaging performance metrology and monitoring for the Library of Congress, Office of Strategic Initiatives. He co-leads the ISO/TC42 standardization efforts on digital print and film scanner resolution (ISO 16067-1, ISO 16067-2), scanner dynamic range (ISO 21550) and is the editor for the second edition of ISO 12233, digital camera resolution. Don also sits on the advisory board of the Federal Agencies Digitization Guidelines Initiative, Still Image Working Group.

Peter Burns is with Carestream Health. His work includes medical and dental image processing, and the development of imaging performance evaluation, analysis and software tools. He also worked in this area at Eastman Kodak and Xerox, and is a frequent speaker at technical conferences. He has taught several imaging courses: at Kodak, SPIE and IS&T Conferences, and at the Center for Imaging Science, RIT.