DIGITAL IMAGING *for* PHOTOGRAPHIC COLLECTIONS

Foundations for Technical Standards

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Foreword

There is a well-known truth among photographers that copy photography—taking a picture of a picture—is technically more difficult than making a portrait or a landscape. It is all too easy in copy work to alter the contrast or lose the fine details of the original. As cultural institutions begin to make digital copies of their photograph collections, they are learning a variant of the old truth: it is as difficult to make good digital copies as good photographic ones. The goal of the NEH-sponsored project that made this publication possible was to offer some guidance to libraries, archives, and museums in their efforts to convert photographic collections to digital form. Specifically, we sought to identify the key issues affecting image quality, clarify the choices facing every digitizing project, and explore ways to measure digital image quality.

Along the way, we learned that one of the most important and difficult questions to answer is what level of quality is really needed in digital image collections. In the hands of expert operators, today's best digital imaging hardware is capable of capturing *all* the information in photographic originals. Such a high quality standard produces the most versatile digital images but requires the storage and manipulation of huge files. A lower quality standard produces more manageable files but often limits the utility of the files for such demanding uses as publication or exhibition. Selecting the appropriate quality level will always depend on careful analysis of the desired uses of the images in the near and long term.

In the project and in this publication, we have sought to clarify not only the qualitative aspects of quality choices, but also the technical and quantitative. Measurements that ensure adequate capture of detail and contrast are in some ways easier and more accurate in digital imaging than in conventional photography because they can be done in software. Only when off-the-shelf software for this purpose becomes available can the full promise of digital imaging for institutional photograph collections be realized.

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Rochester, NY
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INTRODUCTION

The grant project, *Digital Imaging for Photographic Collections: Foundations for Technical Standards was a two-year research study that investigated the use of digital imaging in libraries and archives.*

There are no guidelines or accepted standards for determining the level of image quality required in the creation of digital image databases for photographic collections. Although clear imaging standards are not yet fully in place, and it is difficult to plan in an atmosphere of technological uncertainty, there are some basic rules that can be followed to minimize unexpected results.[1-3] Within this project we began to develop an "image quality framework" that will help with planning parts of digital-imaging projects. Our framework is not meant to be complete and ready to use; more work on various levels is needed. However, fruitful discussions were begun through this work, and we can see some of our ideas being taken forward in other initiatives.

The materials that make up photographs (silver or dyes as image-forming materials; paper, celluloid, or other plastics as base materials; and gelatin, albumen, or collodion as binders) are not chemically stable. Environmental influences such as light, chemical agents, heat, humidity, and storage conditions affect and destroy photographic materials. In a general way, the life span of photographs can be extended only by appropriate storage at low temperatures and low humidity. Storage under controlled climatic conditions does not prevent decay, however; it results, at best, in a significant slowdown. Photographic collections are facing a dilemma: on one hand, photographic documents must be stored under correct climatic conditions, and, on the other hand, it is often necessary to have quick access to them. Frequently, in this situation, an unsatisfactory compromise is made.[4]

The long-term preservation of photographic images is always a very demanding task. The principles of secure preservation for digital data are fundamentally different from those for traditional analogue data.[5-8] First, in traditional preservation there is a gradual decay of image quality, while digital image data either can be read accurately or, in most cases, cannot be read at all. Secondly, every analogue duplication process results in a deterioration of the quality of the copy, while the duplication of the digital image data is possible with no loss at all.

In an idealized traditional archive, the images should be stored under optimal climatic conditions and never touched again. As a consequence, access to the images is severely hindered while decay is only slowed down. A digital archive has to follow a different strategy. The safe keeping of digital data requires an active and regular maintenance of the data. The data have to be copied to new media before they become unreadable. Since information technology is evolving rapidly, the lifetime of both software and hardware formats is generally shorter than the lifetime of the recording media. However, since the digital data can be copied without loss, even if the media type and hardware change, the image is in a "frozen" state, and the decay has completely stopped.

The main difference between a traditional archive and a digital archive is that the traditional archiving approach is a passive one with images being touched as little as possible. Often, however, this works only in theory. If a document is known to be available, it is likely to be used. Therefore, in practice, we see an increased handling of original documents as soon as they become available in digital form. The future will show whether a good enough digitized copy will reduce this behavior.

The digital archive needs an active approach in which the digital data (and the media they are recorded on) is monitored continually. This constant monitoring and copying can be achieved with a very high degree of automation.

One of the big issues that institutions should consider prior to implementing a project is the anticipated use of their digital image collections. Will the images be made accessible on a stand-alone workstation or via the World Wide Web? Will they be used for printing reproductions? What size will the prints be? Are there restrictions on access that must be honored? These are only a few of the questions that have to be answered *before* a digitization project starts.

There is a growing consensus within the preservation community that a number of image files must be created for every photograph to meet a range of uses. First, an

THE ADVANTAGES OF DIGITAL INFORMATION

- Digital data represents a symbolic description of the originals; it can be compared to the invention of writing.
- Digital information can be copied without loss.
- Active sharing of digital images is easily possible.
- New viewing experiences are possible by browsing through a collection without pre-selection by another individual. This will allow a completely different type of intellectual access to pictorial information.

"archive" or master image should be created. It should contain a brightness resolution greater than eight bits per channel, it should not be treated for any specific output in mind, and it should be uncompressed or compressed in a lossless manner. From this archive file various access files can be produced as needed to meet specific uses. The following three examples illustrate the ways in which the intended use drives decisions regarding digital image quality:

- **The digital image is used only as a visual reference in an electronic database.** The required digital image quality is low, in terms of both spatial and brightness resolution content. The display is usually limited to a screen or a low-resolution print device. Thumbnail image size for screen viewing usually does not exceed a width of approximately 250 pixels. If an additional, larger image size is desired for low-resolution previewing on a print device or larger viewing on screen, pixel dimensions of 1024 x 768 are sufficient for most applications. Exact color reproduction is not critical. Additionally, images can be compressed to save storage space and delivery time.
- **The digital image is used for reproduction.** The requirements for the digitizing system will depend on the definition of the desired reproduction. Limiting output to certain spatial dimensions will facilitate the decision-making process. For example, if the output is limited to an 8 x 10 hard copy at a resolution of 300 dots per inch (dpi), the dimensions of the digital file need not exceed 2,400 x 3,000 pixels. Similarly, decisions regarding tonal reproduction are facilitated when modestly sized reproductions in print are the goal of digitization. Currently, most digitizing systems will allow only an eight-bit-per-color output. This is in most cases, a perceptual, not a colorimetric, rendering of the original. It is important to note that if these colors are not mapped correctly, the digital file may not always replicate the tone and color of the original.
- **The digital image represents a "replace-**

DIGITAL MASTER VERSUS DERIVATIVES

- The digital master is the file that is archived. It represents the highest quality file that has been digitized. Since this is the information that is supposed to survive and be taken into the future, the main issues in creating the digital master relate to longevity and quality.
- The derivatives are the files for daily use. Speed of access and transmission and suitability for certain purposes are the main issues to consider in the creation of derivative files.

ment" of the original in terms of spatial and tonal information content. This goal is the most challenging to achieve given today's digitizing technologies and the cost involved. The information content in terms of pixel equivalency varies from original to original. It is defined not only by film format but also by emulsion type, shooting conditions, and processing techniques. Additionally, eight-bit-per-color digital capture might be adequate for visual representation on today's output devices, but it might not be sufficient to represent all the tonal subtleties of the original. Ultimately, "information content" has to be defined, whether based on human perception, the physical properties of the original, or a combination of both.

The Phases of the Project

The first phase of the project involved searching the most recent technical literature, making connections with other people and projects, defining and planning the technical image choices to be explored, setting up an imaging workstation, and having a closer look at the sample images that had been created in another initiative. The rapid and ongoing changes in the field made this a constant task throughout the project.

The main outcome of the second phase was a framework to define subjective and objective image parameters. Because those working with the new imaging technologies are only now beginning to understand all the associated issues, definitions of the parameters and tools to measure them are not readily available. IPI has defined some of the parameters, focusing on the materials found in photographic collections.

The colloquium entitled *Digitizing Photographic Collections—Where Are We Now? What Does The Future Hold?* took place June 7-9, 1997, at Rochester Institute of Technology (RIT). The event received a lot of attention and brought to Rochester over 120 attendees and 20 speakers from around the world.

Background of the Project

RLG Technical Images Test Project

This project was based on the Technical Images Test Project started by a task force of the Research Libraries Group in 1992.[9] The project was designed to explore how image quality is affected by various choices in image capture, display, compression, and output. There are many ways to create and view digital images. The task force felt that, although there was no "best" way for every collection or every project, it would be helpful to define and explore a finite range of practical choices.

The RLG Technical Images Test Project was able to achieve some success in clarifying image quality issues for the initial step of image capture. It also became clear, however, that the given task was much more complex and consumed more time and resources than anticipated.

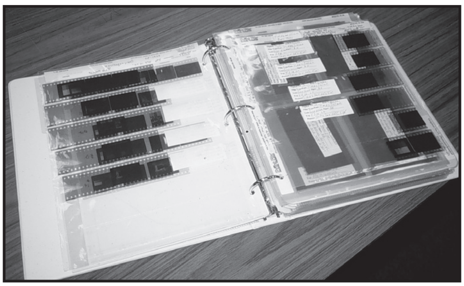


Figure 1. The test images of the RLG technical image project filled a number of binders, since the choices for duplication are numerous.

Evaluation of Image Quality

Fourteen images representing a range of photographic processes and sizes of originals were picked from the IPI study collection. From these photographs were produced negatives, positives, color internegatives, or duplicate transparencies (Figure 1). The same photographs were then used to generate positive photographic prints, in either color or black and white. The basic method of comparing quality resulting from the various intermediate formats and film types was to lay all the prints out on a table under controlled lighting conditions (Figure 2). With the naked eye, with a loupe, or with a stereo microscope, prints were compared to each other two at a time. The sharpness of the same selected details in each print were compared, as were graininess and smoothness of tone. For the color originals and the nineteenth-century processes, color fidelity was also important, but it was recognized that there is an extra layer of difficulty in controlling and judging color fidelity.

Figure 2. Image quality evaluation was performed by subjectively comparing all of the different prints to each other.

Results from Image Comparisons in the RLG Technical Images Test Project

The image comparison exercise showed us that the first important decision to be made at the digital capture stage

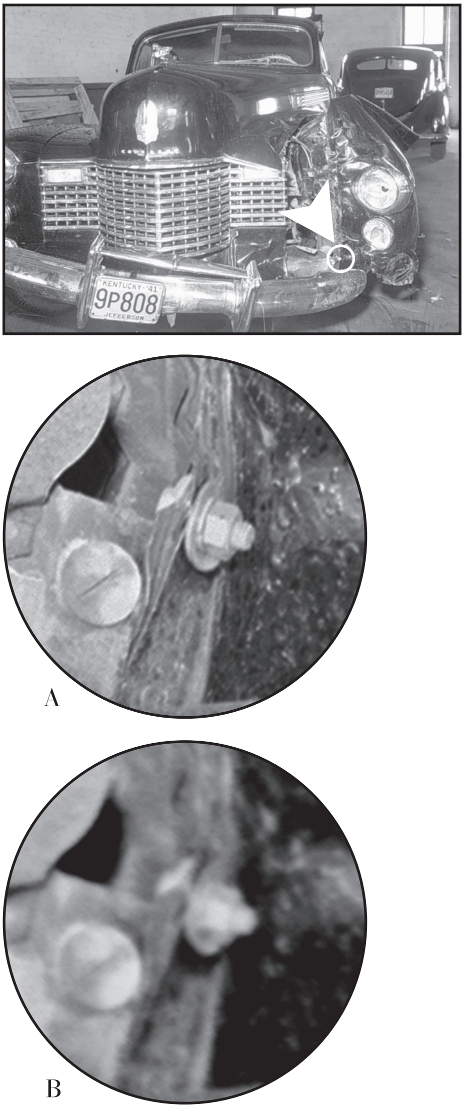


Figure 3. Scanning from original or intermediate? Top image is a contact print from an original 8 x 10 negative. The arrow points to a detail chosen for comparison. Image A shows the selected detail from a scan of the original; image B shows the same detail from a scan of a 35mm intermediate.

is whether digitization should be done directly from the original photographs themselves or from photographic copies, also known as *photographic intermediates (Figure 3). There are advantages and disadvantages to both approaches. Because every generation of photographic copying involves some quality loss, using intermediates immediately implies some decrease in quality. Intermediates may also have other uses, however; for example, they might serve as masters for photographic reference copies or as preservation surrogates.*

This leads to the question of whether the negative or the print should be used for digitization, assuming both are available. As stated above, quality will always be best if the first generation of an image, i.e., the negative, is used. However, it can happen, mainly in the domain of fine-art photography, that there are big differences between the negative and the print. The artist often spends a lot of time in the darkroom creating his prints. The results of all this work are lost if the negative, rather than the print, is scanned. The outcome of the digitization will be disappointing. Therefore, for fine art photographs, scanning from the print is often recommended. Each case must be looked at separately, however.

One of the most important lessons learned in this exercise was that many of the original photographs in institutional collections have truly outstanding image quality. Even using 4 x 5 duplication film, excellent lenses, and the skill and experience of many years of photographic duplication, there was still a quite noticeable loss of image quality in the copying of an original 8 x 10 negative. Other images showed the same results, to varying degrees. This high level of image quality in original photographs sets a very high standard for successful reformatting projects, whether conventional or digital. We must be careful not to "reformat" the quality out of our image collections in the name of faster access. Instead, we must learn what it takes to bring that quality forward for future generations or at least to know that we are failing to do so.

Where We Started

The RLG Technical Images Test Project showed us that the question of image quality cannot be answered in a linear fashion. Scanning, processing, and outputting images involve many different parameters that affect image quality. In any large digital imaging effort, objective parameters and ways to control them must be defined at the outset. IPI's goal was to attempt to quantify image quality by building an image quality framework.

We learned a great deal from this process—most importantly, that there is a lot more work to be done. Calibration issues need to be solved before image quality can be evaluated on a monitor. Methods for testing the capabilities of, or benchmarking, systems must be devised. Most critical of all, a common language in which all involved parties can communicate needs to be developed.

Literature Research and Preparation of Samples

The first phase of the project consisted of examining digital imaging projects in the libraries and archives field. This was accomplished through personal contact with people at institutions conducting such projects, watching various discussion lists and the growing number of museum sites on the Internet, and researching newsletters and scientific journals in the field. Because everything is changing so quickly in the digital field, literature research and examination of digital projects were ongoing tasks, proceeding hand-in-hand with monitoring and learning about new technologies.[10-12]

Significant Projects for This Study

- **National Digital Library Project (NDLP) of the Library of Congress.** The Library plans to convert as many as five million of its more than one hundred million items into digital form before the year 2000. The materials to be converted include books and pamphlets, manuscripts, prints and photographs, motion pictures, and sound recordings. NDLP used part of our image quality approach in their request for proposals and in the process control for their current scanning projects (Figure 4).

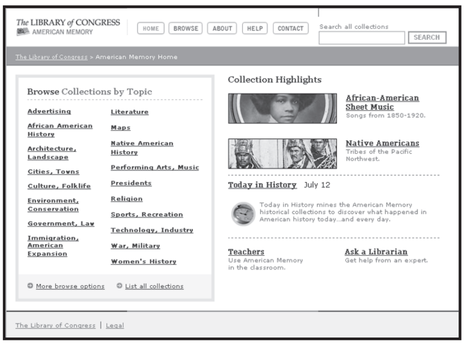


Figure 4. memory.loc.gov/ammem/index.html

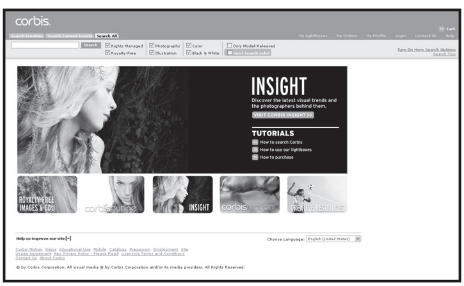


Figure 5. www.corbis.com

- **Corbis Corporation.** Corbis is one of the biggest digital stock agencies in the world. With the incorporation of the Bettmann Archives, Corbis faces new problems similar to the ones archives and libraries have, due to the fact that there is a

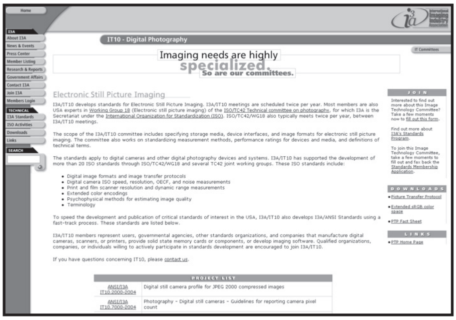
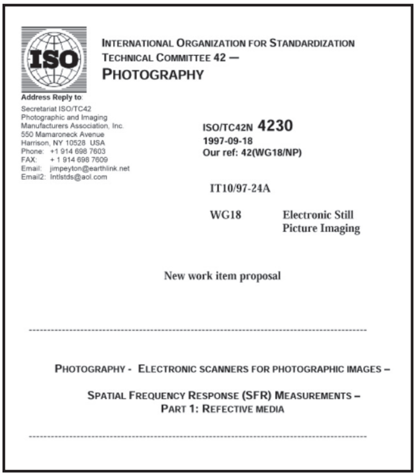


Figure 6. www.i3a.org/it10.html



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WG18 Electronic Still Picture Imaging

New work item proposal

PHOTOGRAPHY - ELECTRONIC SCANNERS FOR PHOTOGRAPHIC IMAGES –
SPATIAL FREQUENCY RESPONSE (SFR) MEASUREMENTS –
PART 1: REFECTIVE MEDIA

Figure 7. IT10 task group for the characterization of scanners. The first work item deals with resolution measurements for scanners.

Figure 8. www.amico.org (In June of 2005, the members of the Art Museum Image Consortium voted to dissolve their collaboration.)

whole new range of materials that will have to be scanned. Contact with Corbis gave us an interesting insight into some of the issues to be faced by a digital stock agency, a company whose ultimate goal is to make money with digitized photographs (Figure 5).

- **Electronic Still Photography Standards Group (ANSI IT10).** The scope of this committee includes specifying storage media, device interfaces, and image formats for electronic still picture imaging. The scope also includes standardizing measurement methods, performance ratings for devices and media, and definitions of technical terms. Within the committee, a new task group for characterization of scanners has been formed.[13] Some of the findings of the current project are being used as a basis for a standard in this area. The cumulative experience that was brought into this project is very valuable and will speed up the publication of much-needed documents (Figures 6 and 7).
- **AMICO (Art Museum Image Consortium).** RIT, together with the Image Permanence Institute, has been selected to be among the participants of the University Testbed Project. AMICO has been formed by twenty-three of the largest art museums in North America. The mission of this nonprofit organization is to make a library of digital documentation of art available under educational license (Figure 8).

The Salient Points

IPI's ongoing review of work in the field showed a growing awareness of the complexity of undertaking a digital conversion project. In addition to the creation of a digital image database, which by itself brings up numerous problems, maintenance of the database over time must be considered. Questions regarding the permanence of the storage media, accessibility, quality control, and constant updating are only a few of those that must be addressed.

We also saw proof that many of the problems arising from the need to scan for an unknown future use are not yet solved and that there is a great deal of uncertainty about how to proceed. Those responsible for some of the big digital reformatting projects report the same problem: rapid changes in the technology make it difficult to choose the best time to set up a reformatting policy that will not be outdated tomorrow.

THE NEED FOR COMMUNICATION

It is up to libraries and archives to tell the hardware and software industries exactly what they need, but before a fruitful dialogue can take place a common language must be developed.

The lack of communication between the technical field and institutions remains a formidable obstacle. It cannot be emphasized enough that if institutions fail to communicate their needs to the hardware and software industries, they will not get the tools they need for their special applications. Archives and libraries should know that they are involved in creating the new standards. It can be seen today that whoever is first on the market with a new product is creating a *de facto* digital technology standard for competitors. Furthermore, time to create new standards is very short; industry will not wait years to introduce a product simply because people cannot agree on a certain issue. Both institutions and industry are interested in a dialogue, but there is no common language.[14-18]

The exponential growth and use of the Internet has raised a whole new range of questions and problems that will have to be solved, but the Internet is also a great information resource.

A digital project cannot be looked at as a linear process, in which one task follows the other. Rather, it has to be looked at as a complex structure of interrelated tasks in which each decision has an influence on another one. The first step in penetrating this complex structure is to thoroughly understand each single step and find metrics to qualify it. Once this is done, the separate entities can be put together in context. We are still in the first round of this process, but with the benefit of all the experience gathered from the various digital projects in the field, we are reaching the point at which the complex system can be looked at as a whole.

Some findings from this project concerning spatial resolution have been used as a basis for the ISO Standard 16067-1:2003, Electronic scanners for photographic images —Spatial resolution measurements: Part 1, Scanners for reflective media.

Building the Image Quality Framework

What Is Image Quality?

According to *The Focal Encyclopedia of Photography*,

> [t]he basic purpose of a photograph is to reproduce an image. One of the three basic attributes of a reproduction image is the reproduction of the tones of the image. Also of importance are the definition of the image (the reproduction of edges and detail and the amount of noise in the image) and the color reproduction. It is convenient to deal with these attributes when evaluating an image.[19]

Image quality is usually separated into two classes:

- **Objective image quality** is evaluated through physical measurements of image properties. Historically, the definition of image quality has emphasized image physics (physical image parameters), or objective image evaluation.
- **Subjective image quality** is evaluated through judgment by human observers. Stimuli that do not have any measurable physical quantities can be evaluated by using psychometric scaling test methods. The stimuli are rated according to the reaction they produce on human observers. Psychometric methods give indications about response differences. Psychophysical scaling tools to measure subjective image quality have been available only for the last 25 to 35 years.[20]

Quantification of image quality for the new imaging technologies is a recent development.[21-24] The theoretical knowledge and understanding of the different parameters that are involved is available now. Still missing for the practitioner of digital imaging are targets and tools to objectively measure image quality. These tools are available only within the companies that manufacture imaging systems and are used mostly to benchmark the companies' own systems. Furthermore, in most cases, the systems being used for digital imaging projects are open systems, which means that they include modules from different manufacturers. Therefore, the overall image quality performance of a system cannot be predicted from the manufacturers' specifications, since the different components influence each other.

It should be kept in mind that scanning for an archive is different from scanning for prepress purposes.[25] In the latter case, the variables of the scanning process are well known, and the scanning parameters can be chosen accordingly. If an image is scanned for archival purposes, the future use of the image is not known, and neither are technological changes that will have taken place a few years from now. This leads to the conclusion that decisions concerning the quality of archival image scans are very critical.

As seen at various conferences, this is a relatively new concept for both the institutions and the technical field, and it will take some work to help both sides understand where the problems are. This is a topic for more research. The ANSI Standards task group for the characterization of scanners has contributed to the technical community's awareness of the issue.

Image quality evaluations are important at two different stages of a project: at the beginning, to benchmark the system that will be used, and later, to check the images that have been produced.[26,27]

Digital Image Quality and Its Implications for an Imaging Project

There are no guidelines or accepted standards for determining the level of image quality required in the creation of digital image databases for access or preservation of photographic collections. As a result, many institutions have already been disappointed because their efforts have not lead to the results they were hoping for. Either the parameters chosen for the digitization process were not thought through, or the technology changed after the project started. In the first case, the failures might have been prevented. No one knows what technology will be available in a few years, however, and the task of choosing the right scanning parameters still needs to be researched. One problem is that we are currently at the beginning of the cycle of understanding image quality for the new imaging technologies.

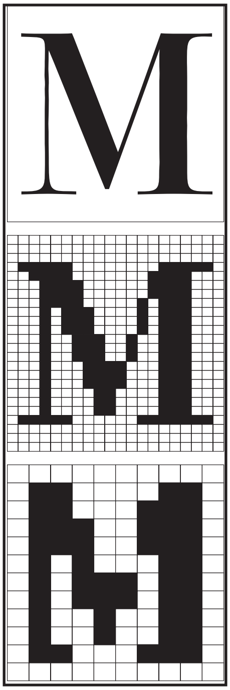


Figure 9. The main quality issue for reformatted paper documents is legibility. The higher the ppi, the more details of the character can be resolved. The needed ppi can be calculated for a known character height.

Often, imaging projects start with scanning text documents. When this type of material is scanned, quality is calculated according to a "Quality Index," which is based on published guidelines for microfilming (Figure 9).

> Quality Index is a means for relating resolution and text legibility. Whether it is used for microfilming or digital imaging, QI is based on relating text legibility to system resolution, i.e., the ability to capture fine detail.[28]

There is no common unit like character size that can ensure the semantic fidelity of images. The quantitative solutions that have evolved from scanning text therefore do not have a logical or practical fit with capturing images.[29] This means that other ways have to be found for the evaluation of the quality of an image and for determining how much of the image information is conveyed in the digital reproduction.

The more one looks at image quality and ways to clearly define it, the more parameters have to be taken into account. We have tried to develop a balanced approach that is not only usable in the archives and libraries world but also as complete as possible from an engineering point of view.

In addition, when looking at image quality, the whole image processing chain has to be examined. Besides issues concerning the scanning system, IPI has looked at compression, file formats, image processing for various uses, and system calibration.

One of the big issues is that institutions will have to decide beforehand on the use of their digital images. This still creates a lot of questions and problems. Sometimes, how images will be used is not clear when a project starts. More often, however, institutions don't take enough time to think about the potential use of the digital images. Furthermore, institutions often have unrealistic expectations about digital projects. Even if the goals have been carefully defined, costs may not be worked out accordingly, or goals may not match the available funds.

Although the ease of use of many digitizing systems has fostered the perception that scanning is "simple," successfully digitizing a photographic collection requires as much experience as conventional reformatting.[30] Further, most of the available scanning technology is still based

How Big Is the Collection?

When choosing a digitizing system, bear in mind that approaches that work for a small number of images may not work for a large number of images. Very sophisticated systems can be set up in a laboratory environment for a small number of images. Large numbers of images need a well thought out workflow.

on the model of immediate output on an existing output device with the original on hand during the reproduction process. Spatial resolution and color mapping are determined by the intended output device. Depending on the quality criteria of the project, a more sophisticated system and more expertise by the operator are needed to successfully digitize a collection in an archival environment where the future output device is not yet known. The characteristics of scanning devices such as optical resolution, dynamic range, registration of color channels, bit-depth, noise characteristics, and quantization controls need to be carefully evaluated with consideration of the final use of the digital images.

When choosing the digitizing system, it also must be remembered that approaches that work for a small number of images may not be suitable for the large number of images usually found in collections.

Building Visual Literacy

Looking at images and judging their quality has always been a complex task. The viewer has to know what he/she is looking for. The visual literacy required when looking at conventional images needs to be translated for digital images. Much more research is needed to enable us to fully understand the ways in which working with images on a monitor differ from working with original photographs.

Subjective Image Quality Evaluation

In most cases, the first evaluation of a scanned image will be made by viewing it on a monitor (Figure 10). The viewer will decide whether the image on the monitor fulfills the goals that have been stated at the beginning of the scanning project. This is important, because human judgment decides the final acceptability of an image. It should be emphasized that subjective quality control must be executed on calibrated equipment, in an appropriate, standardized viewing environment. If tone and color are evaluated, it may be necessary to transform data to suit display viewing conditions.

While the image is viewed on the monitor, defects such as dirt, "half images," skew, and so on, can be detected. In addition, a target can be used to check the registration of the three color channels for color scans. It

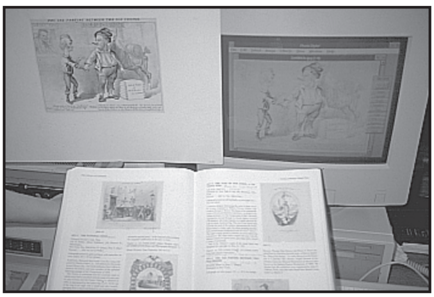


Figure 10. How not to do it: comparison of the original printed reproduction and a digital image on the monitor. To be done correctly, subjective image quality evaluation requires a standardized environment with calibrated monitors and dim room illumination.

is also important to check visual sharpness at this point. Mechanical malfunction of the scanner or limited depth of field could cause images to lack sharpness.

Definition of the Parameters for Evaluating Technical Pictorial Quality

There are four main parameters to consider when assessing the technical pictorial quality of an image. Due to the lack of off-the-shelf software and targets to evaluate the quality parameters, IPI had to create its own software tools and targets. As a result, two parameters, tone reproduction and detail and edge production, became the focus of the project.

- **Tone reproduction.** This refers to the degree to which an image conveys the luminance ranges of an original scene (or of an image to be reproduced in case of reformatting). It is the single most important aspect of image quality. Tone reproduction is the matching, modifying, or enhancing of output tones relative to the tones of the original document. Because all of the varied components of an imaging system contribute to tone reproduction, it is often difficult to control.
- **Detail and edge reproduction.** Detail is defined as relatively small-scale parts of a subject or the images of those parts in a photograph or other reproduction. In a portrait, detail may refer to individual hairs or pores in the skin. Edge reproduction refers to the ability of a process to reproduce sharp edges (the visual sharpness of an image).
- **Noise.** Noise refers to random variations associated with detection and reproduction systems. In photography, the term *granularity* is used to describe the objective measure of density nonuniformity that corresponds to the subjective concept of graininess. In electronic imaging, noise is the presence of unwanted energy fluctuation in the signal. This energy is not related to the image signal and degrades it.
- **Color reproduction.** Several color reproduction intents can apply to a digital image. *Perceptual intent*, *relative colorimetric intent*, and *absolute*

colorimetric intent are the terms often associated with the International Color Consortium (ICC). Perceptual intent is to create a pleasing image on a given medium under given viewing conditions. Relative colorimetric intent is to match, as closely as possible, the colors of the reproduction to the colors of the original, taking into account output media and viewing conditions. Absolute colorimetric intent is to reproduce colors as exactly as possible, independent of output media and viewing conditions.

These parameters will be looked at in greater detail in a later section.

The Role of Targets in Evaluation of the Image Quality Parameters

Targets are a vital part of the image quality framework. To be able to make objective measurements of each of the four parameters, different targets for different forms of images (e.g., prints, transparencies, etc.) are needed. To get reliable results, the targets should consist of the same materials as those of the items that will be scanned—photographic paper and film. After targets are scanned they are evaluated with a software program. Some software components exist as plug-ins to full-featured image browsers, others as stand-alone programs.

Targets can be incorporated into the work flow in various ways. Full versions of the targets might be scanned every few hundred images and then linked to specific batches of production files, or smaller versions of the targets might be included with every image. The chosen method will depend on the individual digital imaging project.

As more institutions initiate digitization projects, having an objective tool to compare different scanning devices will be more and more important. Until now, scanner manufacturers usually have used their own software when evaluating and testing systems.

For the current project, IPI examined approaches taken by other research projects in similar areas and looked carefully at a variety of targets. Some targets were already available for other purposes and could be purchased; some had to be custom-made. A set of targets with software to read them are available on the market (see page 45).

The use of objective measurements resulting from the target evaluation will be twofold. Some of the results, together with additional information like spectral sensitivities and details about the actual image processing chain, will be used to characterize the scanning system. This assumes that spectral sensitivities are known and that a complete description of the image processing chain is at hand. These requirements are not often fulfilled, however, since scanner manufacturers are reluctant to provide this information. Other results of the target evaluation will be associated with each image file; this information will be used to perform data corrections later on as the images are processed for output or viewing. Therefore, standardized approaches and data forms are required for interchangeability of the data.

In "Specifics of Imaging Practice," M. Ester wrote:

> If I see shortcomings in what we are doing in documenting images, they are traceable to the lack of standards in this area. We have responded to a practical need in our work, and have settled on the information we believe is important to record about production and the resulting image resource. These recording procedures have become stable over time, but the data would become even more valuable if there was broad community consensus on a preferred framework. Compatibility of image data from multiple sources and the potential to develop software around access to a common framework would be some of the advantages.[31]

New file formats like TIFF/EP,[32] that include a large number of defined header tags, will facilitate the standardized storage of image attribute information (administrative metadata), which, in turn, will facilitate future image processing. Applications do not yet support TIFF/EP, but it is important that collection managers are aware of these possibilities and start to incorporate these ideas into their digital projects.

Discussions with people in the field have shown that there is still some confusion about the role targets play in the digital imaging process. It is important to emphasize that *targets are about the scanning system and not about collections*. This means that the target evaluations are primarily aimed at characterizing scanning systems.

At this time, many aspects of scanning photographs still require the intervention of a well-trained operator. In a few years, some of these tasks will be automated, and manual interventions will be less and less necessary. One could say that targets will then be about collections, because no matter what original is scanned, it will automatically turn out right. However, targets will always be useful for checking the reproduction quality of the digital files, e.g., for confirming that aim-point values are actually reached. This does not mean that scanning is done entirely "by the numbers," because an operator will still be needed to decide when to consciously intervene to improve the subjective quality of the image. This does not apply if 16-bit data are stored.

Figure 11. The three images show different reproduction of the gray tones. The image on the left is too light. The one on the right has no details in the shadow areas and is too dark overall. The one in the middle shows the most acceptable tone reproduction.

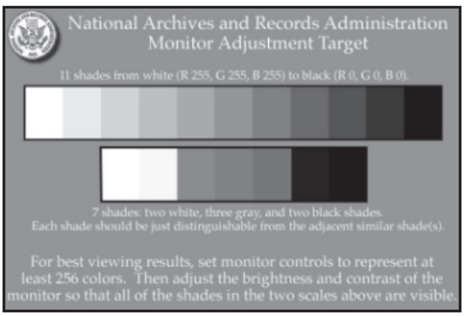


Figure 12. Tone reproduction control targets for users looking at images on monitors are important quality control tools. This sample shows a gray wedge that is available on the National Archives web site (www.archives.gov/research/arc/adjust-monitor.html). *The user is asked to change brightness and contrast on the monitor screen in order to see all steps on the gray wedge target. It is important to remember that images may have to be processed for viewing on a monitor.*

The Parameters of the Image Quality Framework

Tone Reproduction

Tone reproduction is the single most important parameter for determining the quality of an image. If the tone reproduction of an image is right, users will generally find the image acceptable, even if some of the other parameters are not optimal (Figures 11 and 12).

Tone reproduction is applicable only in the context of capture and display. This means that an assumption must be made regarding the final viewing device. Three mutually dependent attributes affect tone reproduction: the opto-electronic conversion function (OECF), dynamic range, and flare. OECF can be controlled to a certain extent via the scanning software but is also dependent on the A/D (analog to digital) converter of the scanning system; dynamic range and flare are inherent in the scanner hardware itself.

The OECF shows the relationship between the optical densities of an original and the corresponding digital values of the file. It is the equivalent of the D-log H curve in conventional photography (Figure 13). Dynamic range refers to the capacity of the scanner to capture extreme density variations. The dynamic range of the scanner should meet or exceed the dynamic range of the original. Flare is generated by stray light in an optical system. Flare reduces the dynamic range of a scanner.

The most widely used values for bit-depth equivalency of digital images is still eight bits per pixel for monochrome images and 24 bits for color images. These values

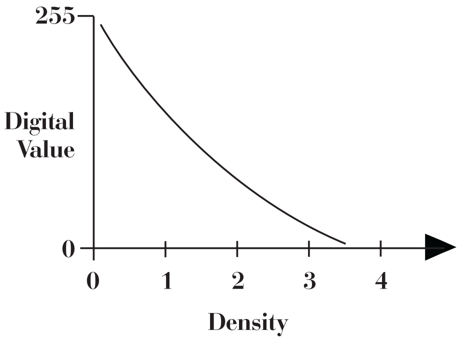


Figure 13. Using a calibrated gray scale target and the resulting digital values, the tone reproduction of the scanning device can be determined. The reflection or transmission density of each step of the gray scale can be measured with a densitometer. Plotting these values against the digital values of the steps in the image file show the performance of the scanning device over the whole range of densities.

Figure 14. Calibrated gray-scale test targets serve as a link back to the reality of the original document or photograph.

are reasonably accurate for good-quality image output. Eight bits per channel on the input side is not sufficient for good-quality scanning of diverse originals. To accommodate all kinds of originals with different dynamic ranges, the initial quantization on the CCD side must be larger than eight bits.

CCDs work linearly to intensity (transmittance or reflectance). To scan images having a large dynamic range, 12 to 14 real bits (bits without noise) are necessary on the input side. If these bits are available to the user and can be saved, it is referred to as having access to the *raw scan*.

High-bit-depth information is very important, especially in the case of negatives. Negatives can be considered a photographic intermediate; they are not yet finalized for an "eye-pleasing" image like prints and slides. Negatives show a high variability. They can have low contrast, high contrast, and everything in between. The dark parts of the negatives contain the important image information. Only very good scanners can resolve very well in these dark parts of the originals. The scanner needs a high dynamic range and not a lot of flare to produce real, noise-free, high-bit information.

Often, it is only possible to get eight-bit data out of the scanner. The higher-bit file is reduced internally. This can be done in different ways. The scanner OECF shows how this is done for a specific scanner at specific settings. It is often done nonlinearly (nonlinear in intensity, but linear in lightness or brightness, or density), using perceptually compact encoding. A distribution of the tones linear to the density of the original leaves headroom for further processing, but, unless the images and the output device have the same contrast, the images will need to be processed before viewing. Processing images to look good on a monitor will limit certain processing possibilities in the future.

The data resulting from the evaluation of the OECF target is the basis for all subsequent image quality parameter evaluations, e.g., resolution. It is therefore very important that this evaluation is done carefully.
In cases where data is reduced to eight bits, the OECF data provide a map for linearizing the data to intensity (transmittance or reflectance) by applying the reverse OECF function. This step is needed to calculate all the other parameters. In the case of 16-bit data, linearity to

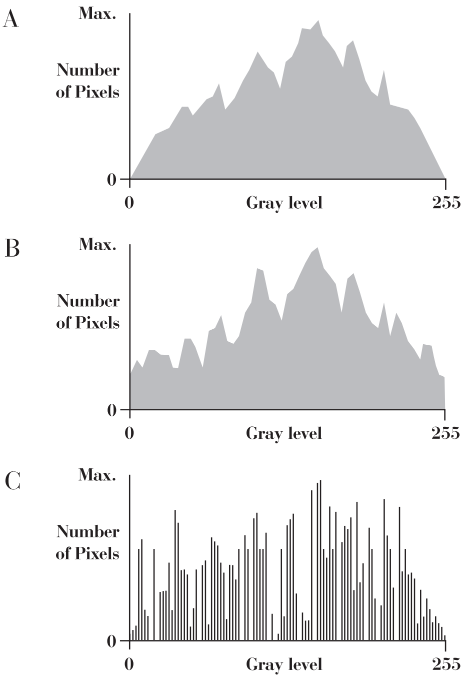


Figure 15. Histograms of the image files can be used to check whether all digital levels from 0 to 255 are used (A), whether any clipping (loss of shadow and/or highlight details) occurred during scanning (B), or whether the digital values are unevenly distributed as can be the case after image manipulation (C).

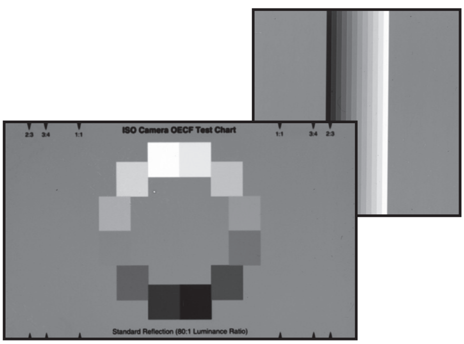


Figure 16. Targets for measuring linearity of the scanning system. The target on the lower left is for use with digital cameras, and the one on the upper right is for use with line scanners.

transmittance and reflectance will be checked with the OECF data. Any processing to linearize the data to density will follow later.

Reproducing the gray scale correctly often does not result in optimal reproduction of the images. However, the gray scale can be used as a trail marker for the protection of an institution's investment in the digital scans (Figure 14); having a calibrated gray scale associated with the image makes it possible to go back to the original stage after transformations, and it also facilitates the creation of derivatives. The gray scale could be part of the image, or the file header could contain the digital values.

Tone and color corrections on eight-bit images should be avoided. Such corrections cause the existing levels to be compressed even further, no matter what kind of operation is executed. To avoid the loss of additional brightness resolution, all necessary image processing should be done on a higher-bit-depth file. Requantization to eight-bit images should occur after any tone and color corrections.

Often, benchmark values for the endpoints of the RGB levels are specified by the institution. The National Archives, for example, ask in their guidelines for RGB levels ranging from 8 to 247.[33] The dynamic headroom at both ends of the scale is to ensure no loss of detail or clipping in scanning and to accommodate the slight expansion of the tonal range due to sharpening or other image processing steps (Figure 15).

Additionally, as part of the tone reproduction test, the flare of the system can be tested. Flare exists in every optical system, reducing the contrast of the original.

Targets to Use

- **OECF target for measuring linearity.**[34] This target (Figure 16) characterizes the relationship between the input values and the digital output values of the scanning system. It is used to determine and change the tone reproduction. The target was developed based on the ongoing research of the Electronic Still Photography Standards Group (ISO/TC 42/WG18). The target has been manufactured under IPI's guidance by a company in Rochester. Since the specifications in the standard are tight, the production process proved to be lengthy.
- **Flare measurement target.** A flare model can

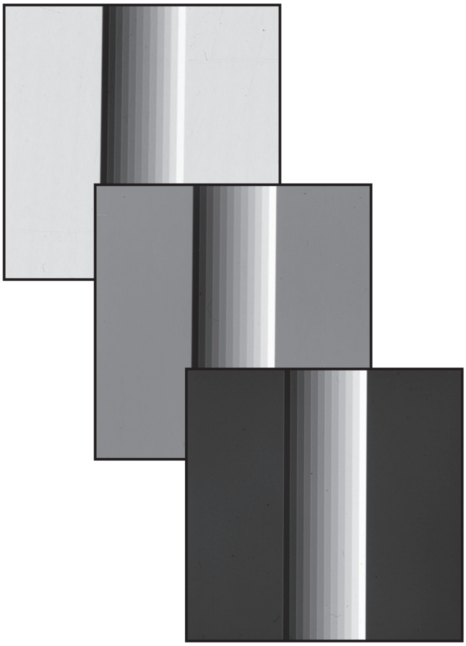


Figure 17. Tone reproduction targets can be used to build a flare model for the scanning system. This requires targets with different contrast and different backgrounds.

be determined with the various tone reproduction targets. Targets with different backgrounds and different dynamic ranges of the gray patches had to be manufactured (Figure 17).[34]

Another approach consists of using a target with an area of D_{min} and an area of D_{max} allowing the measurement of the flare, i.e., showing how much the original contrast is reduced in the digital file (see Figure 28 on page 24).

In addition, this target can be used to check the registration of the three color channels for color scans. In case of misregistration, color artifacts will appear at the edges. They can also be calculated (see ref. 34, Annex C).

Detail and Edge Reproduction (Resolution)

Monitoring digital projects showed that people are most concerned about spatial resolution issues. This is not surprising, because, of all the weak links in digital capture, spatial resolution has been the best understood by most people. Technology has evolved, however, and today "reasonable" spatial resolution is neither extremely expensive nor does it cost a lot to store the large data files. Because questions concerning spatial resolution came up so often, we looked at this issue very closely. Spatial resolution is either input- or output-oriented. In the former case, the goal is to capture all the information that is in the original photograph; in the latter case, the scanning resolution is chosen according to a specific desired output.

Spatial resolution is the parameter to define detail and edge reproduction.[35] Spatial resolution of a digital image, i.e., the number of details an image contains, is usually defined by the number of pixels per inch (ppi). Spatial resolution of output devices, such as monitors or printers, is usually given in dots per inch (dpi).

To find the equivalent number of pixels that describe the information content of a specific photographic emulsion is not a straightforward process. Format of the original, film grain, film resolution, resolution of the camera lens, f-stop, lighting conditions, focus, blur, and processing have to be taken into consideration to accurately determine the actual information content of a specific picture. The following table gives an idea of the pixel equivalencies for various film types

Sampling Resolution for Extraction of the Film Resolution

Film speed very low (<64 ISO): 3500-5000 pixels/inch
Film speed medium (200-320): 2000-2500 pixels/inch

Source: Jack Holm, HP Research Labs, *The Evaluation of Digital Photography Systems, Short Course Notes*, IS&T 49th Annual Conference, May 1996.

Another common question that should be answered before digitization starts is, given the spatial resolution of the files, how big an output is possible from the available file size? The relationship between the size of a digital image file, its total number of pixels, and consequently its maximum output size at different spatial resolutions can be analyzed mathematically.

To answer the question, the distinction has to be made between continuous-tone and halftone output. For optimal continuous-tone output the ratio between output dots and image pixels should be 1:1. In the case of printing processes that require halftone images, between 1.5:1 and 2:1 oversampling (pixels per inch of the digital file is one and a half to two times greater than dots per inch of the output) is needed.

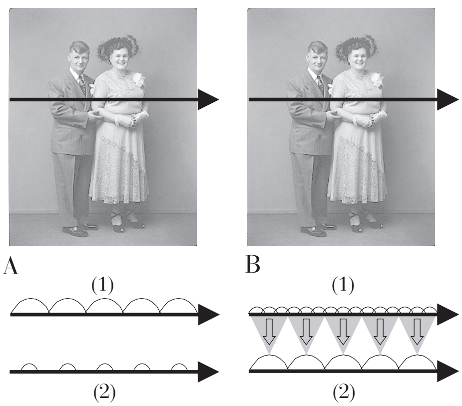


Figure 18. The number of sampling points within a given distance is referred to as the device's digital resolution. In A(1), the digital resolution is low, and not all the image information will be included in the digital file. However, scanners often do not scan correctly at low resolution, showing the behavior depicted in A(2). Since the pixel values are taken over a certain distance and not averaged over a certain area, the quality of the low-resolution image in A(2) will be lower than in A(1). B(1) is sampled with a higher resolution. A low-resolution derivative, B(2), that is calculated from this high-resolution file (using a resampling algorithm) will have a higher quality than the image originally scanned at low resolution with method A(2).

What is Digital Resolution?

Why do we measure resolution? We do so, first, to make sure that the information content of the original image is represented in the digital image and, second, to ensure that the scanning unit used to digitize the image is in focus.

Unlike photographic resolution, digital resolution does not depend on visual detection or observation of an image. Digital resolution is calculated directly from the physical center-to-center spacing between each sample or dot. This spacing is also called the *sampling interval (Figure 18)*.

The number of sampling points within a given distance (usually an inch) is referred to as the device's digital resolution, given in ppi. Digital resolution quantifies the number of sampling dots per unit distance while photographic resolution quantifies observed feature pairs per unit distance, as in line pairs per millimeter (lp/mm).

Translating between units of classical resolution and digital resolution is simply a matter of "two." Dividing digital resolution values in half will yield units that are equivalent to photographic resolution. But there are con-

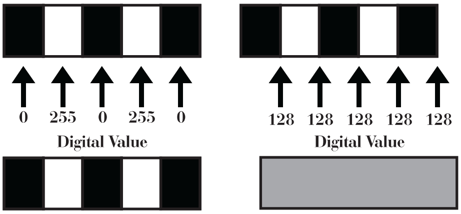


Figure 19. Misregistration between the detectors and the lines of the target by half a pixel can lead to the situation where the black-and-white lines of the original cannot be resolved and will look like a gray field in the digital image (all the digital values are the same, i.e., 128).

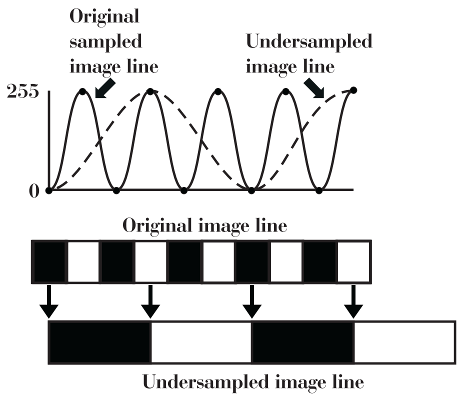


Figure 20. Aliasing occurs when an image is insufficiently sampled. The samples will show up as a lower frequency. Example: An original has 500 line pairs per inch. This represents a function with 500 cycles per inch. To capture all the information (all the valleys and peaks of the function), at least 1000 pixels per inch are necessary; this is the so-called "sampling rate" (1000/25.4=40 pixels per mm). The maximum frequency a sampling device can capture is ½ the sampling rate. This is called the Nyquist frequency. In practice, more pixels per inch are necessary to capture all the information faithfully. In this sample the 1000-ppi device has a Nyquist frequency of 500 line pairs per inch.

ceptual differences between the two that have to be kept in mind when using digital resolution. A misregistration between image details and image sensors may give the impression that a certain device has less resolution than it actually has. Furthermore, aliasing is an issue.

In an ideal scan, the detectors and the lines of the target are perfectly aligned. The concept of misregistration can be easily shown by scanning a bar target. The detectors will only sense the light intensity of either the black line or the white space. If there is a misregistration between the centers of the lines and spaces relative to the detector centers, say by half a pixel, the outcome is different (Figure 19). Now each detector "sees" half a line and half a space. Since the output of every detector is just a single value, the intensities of the line and the space are averaged. The resulting image will therefore have the same digital value in every pixel. In other words, it will look like a gray field. The target would not be resolved. Therefore, the misregistration manifests itself as a contrast or signal loss in the digital image that affects resolution. Since it is impossible to predict whether a document's features will align perfectly with the fixed positions of a scanner's detectors, more than two samples per line pair are required for reliable information scanning.

If the sampling interval is fine enough to locate the peaks and valleys of any given sine wave, then that frequency component can be unambiguously reconstructed from its sampled values. This is referred to as *Nyquist frequency*. Aliasing occurs when a wave form is insufficiently sampled (Figure 20). If the sampling is less frequent, then the samples will be seen as representing a lower-frequency sine wave.

The most noticeable artifact of aliasing is high spatial frequencies appearing as low spatial frequencies. After the wave form has been sampled, aliasing cannot be removed by filtering.

How Is Digital Resolution Measured?

The fundamental method for measuring resolution is to capture an image of a suitable test chart with the scanner being tested. The test chart must include patterns with sufficiently fine detail, such as edges, lines, square waves, or sine-wave patterns.

The Modulation Transfer Function (MTF)

The best overall measure of detail and resolution is the

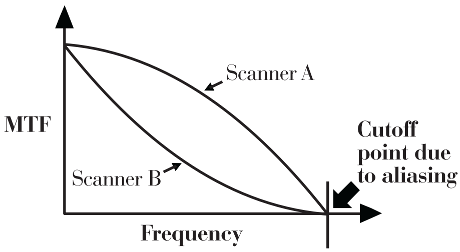


Figure 21. Graph of the modulation transfer function. The MTF shows the performance of two scanning systems over the whole range of frequencies (in the target represented by sine waves that are closer and closer together). The cutoff point of the system represents the highest frequency (the finest image details) that the scanner is able to resolve. An MTF specification to be met by vendors must be established. Scanner A has a better performance than Scanner B; scans from Scanner A will appear sharper.

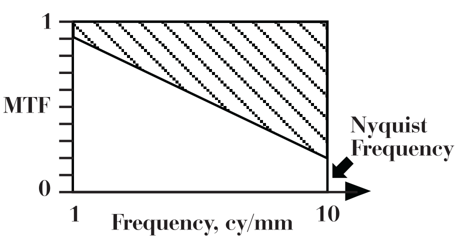


Figure 22. Graph of the modulation transfer function for comparison of different imaging systems. If the tested system shows MTF values above the straight line (area with pattern), it performs well enough. The numbers in this figure apply for scanning at 500 ppi.

modulation transfer function or MTF. MTF was developed to describe image quality in classical optical systems—so-called *linear* systems. The MTF is a graphical representation of image quality that eliminates the need for decision-making by the observer. The test objects are sine-wave patterns.[36-42]

If the MTF is measured for a sampled-data system that is nonlinear, we are talking about the spatial frequency response (SFR) of the system. The terms MTF and SFR are used interchangeably. The measured results for a sampled-data system will depend on the alignment of the target and the sampling sites. An average MTF can be defined, assuming that the scene being imaged is randomly positioned with respect to the sampling sites.

$$MTF = \frac{Output\ Modulation}{Input\ Modulation}$$

(across a range of frequencies)

The MTF is a graph that represents the image contrast relative to the object contrast on the vertical axis over the range of spatial frequencies on the horizontal axis, where high frequency in the test target corresponds to small detail in an object (Figures 21 and 22).

The MTF should be determined and reported for both horizontal and vertical scan directions, since the results can differ.

MTF is difficult and cumbersome to measure in images on photographic materials, requiring special equipment, like a microdensitometer. It is relatively easy to measure in digital images, however.

There are two approaches to defining the MTF of an imaging system. One is to use a sine-wave pattern (Figures 23–26),[43] the other is to use a slanted edge (Figures 27 and

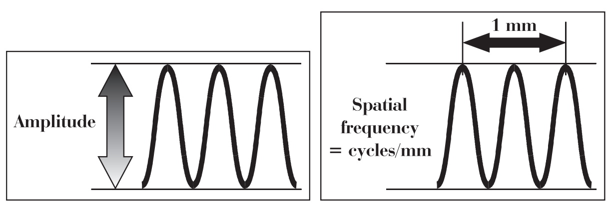


Figure 23. A wave is characterized by its amplitude and its spatial frequency.

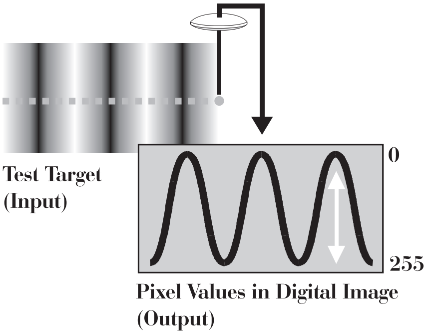


Figure 24. The sine waves of the test target are scanned and translated into digital values. If you were to measure how dark or light the image is at every point along a line across the bars, the plot of these points would be a perfect sine wave.

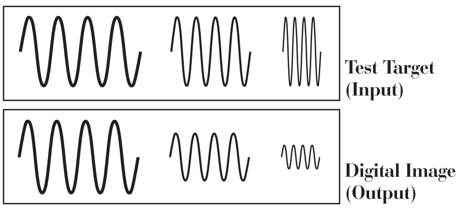


Figure 25. Input modulation/output modulation

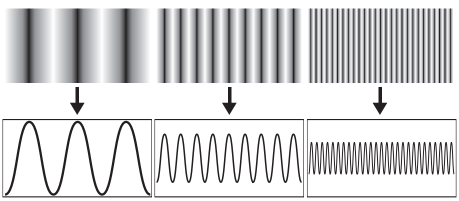


Figure 26. As the bars of the sine-wave target get closer together at higher frequencies, the modulation (i.e., variation from black to white) that is recorded by the scanner gets smaller and smaller.

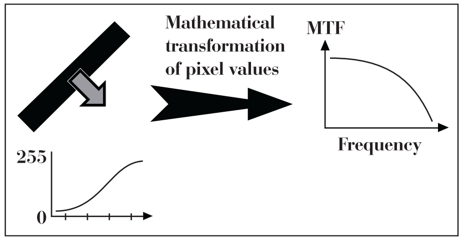


Figure 27. Calculating the MTF using the moving knife-edge method. Pixel values across a slanted edge are digitized and, through a mathematical transformation of these values into the Fourier domain, the MTF of the system can be calculated.

28).[44,45] In the latter case, pixel values near slanted vertical and horizontal black-to-white edges are digitized and used to compute the MTF values. The use of a slanted edge allows the edge gradient to be measured at many phases relative to the image sensor elements, in order to eliminate the effects of aliasing. (This technique is mathematically equivalent to performing a "moving knife-edge measurement.")

Figure 28. Knife-edge target for resolution measurement. Can also be used for flare measurement.

Targets to Use

At this time, the bar targets designed for measurement of photographic resolution often are used to measure digital resolution (Figure 29). These targets are not suitable for this task, except for visually checking aliasing. Visually checking bar targets is not an easy task; the observer must know what to look for. *Therefore, to measure digital resolution of sampling devices another approach has to be taken using slanted edges or sine-wave patterns.*

- **Knife-edge target for resolution measurement.** A knife-edge target has been developed by the Electronic Still Photography Standards Group (Figure 30). A special target (QA-62) for testing scanners is available now as well. We used another target (Figure 28) that looks like the one used for flare measurements. It has been thoroughly tested using a specially developed software module.[46] Tests showed that the target in its current form

Figure 29. Bar targets with converging lines, like this star pattern, can be used to visually check the so-called cutoff frequency of the system (i.e., the smallest features that can be resolved), but they cannot be used to get information on how the system is working for all the different frequencies in the image.

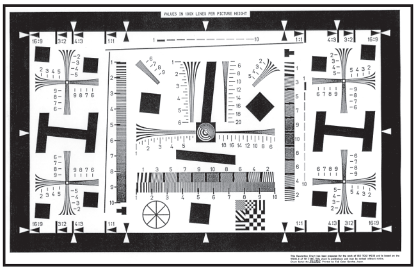


Figure 30. Resolution test chart developed for electronic still photography. The black bars are used to calculate the modulation transfer function.

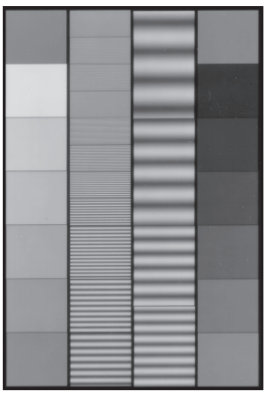


Figure 31. Sine Patterns sine-wave target. The sine waves in the two center rows of the image are used to calculate the MTF.

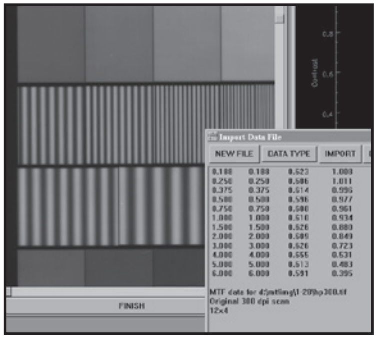


Figure 32. Software interface to compare MTF calculations from sine-wave target and knife-edge target.

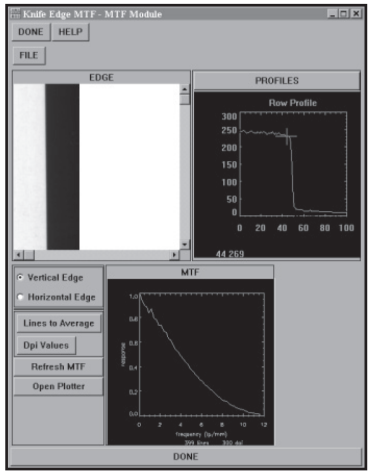


Figure 33. User interface of the software tool to measure MTF from a knife-edge target developed at IPI.

is usable for a scan resolution of up to 600 dpi. This is due to limitations in the in-house production process. Plans for developing a test target for higher scanning resolution were abandoned.

- **Sine-wave target by Sine Patterns Inc. for resolution measurements.** This target (Figure 31) exists on photographic paper and film in different formats. For analysis of the sine-wave target, software developed by MITRE was used.[47]

After testing and comparing the sine-pattern and knife-edge techniques for determining MTF, IPI decided to include both methods in the test (Figures 32 and 33). The results indicated that both methods produce similar MTF characterizations under proper scanning conditions. It was found that the two methods responded differently to image sharpening, nonlinear output gamma mapping, and improper resampling methods. The advantage of using both methods simultaneously lies in the ability to detect undesirable post-scan processing that has been intentionally or unintentionally applied. The software module developed at IPI to calculate the MTF for a knife edge can also compare the sine-wave and knife-edge techniques.

Noise

As defined earlier, noise refers to random signal variations associated with detection and reproduction systems. In conventional photography, noise in an image is the graininess that can be perceived; it can be seen most easily in uniform density areas. The objective measure is granularity. In electronic imaging, noise is the presence of unwanted energy in the image signal (Figure 34).

Noise is an important attribute of electronic imaging systems.[48] Standardization will assist users and manufacturers in determining the quality of images being produced by these systems.[49,50] The visibility of noise to human observers depends on the magnitude of the noise, the apparent tone of the area containing the noise, the type of noise, and the noise frequency. The magnitude of the noise present in an output representation depends on the noise present in the stored image data, the contrast amplification or gain applied to the data in processing, and the noise inherent in the output process and media. Noise visibility is different for the luminance (monochrome) channel and the color channels.

The result of the noise test is twofold. First, it shows the noise level of the system, indicating how many bit levels of the image data are actually useful. For example, if the specifications for a scanner state that 16 bits per channel are recorded on the input side, it is important to know how many of these bits are actual image information and how many are noise; in most cases, two bits are noise. For image quality considerations, the signal-to-noise ratio (S/N) is the important factor to know. The noise of the hardware used should not change unless the scanner operator changes the way she/he works or dirt is built up in the system.

There exist different types of noise in an imaging system. The following definitions are part of the forthcoming standard for noise measurement.

- **Total noise.** All the unwanted variations captured by a single exposure (scan).

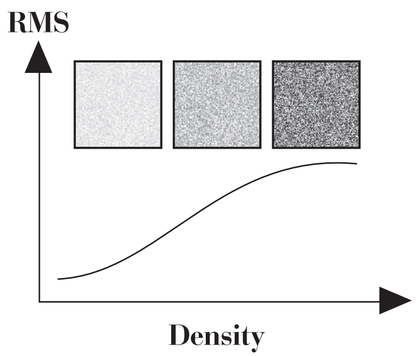


Figure 34. Noise refers to random signal variations in electronic imaging systems, represented as a random pattern in the uniform gray patterns. This graph shows the RMS (root mean square) error, a statistical evaluation representing noise over the density levels of the original image. An RMS of 0 is equal to no noise.

- **Fixed pattern noise.** The unwanted variations that are consistent for every exposure.
- **Temporally varying noise.** Random noise due to sensor dark current, photon shot noise, analogue processing, and quantization that varies from one image to the next.

All of these parameters should be measured and the three above-described signal-to-noise ratios reported for the imaging system.

Since many electronic imaging systems use extensive image processing to reduce the noise in uniform areas, the noise measured in the different large area gray patches may not be representative of the noise levels found in scans from real scenes. Therefore, another form of noise, so-called *edge noise*, will have to be looked at more closely in the future.

Target to Use

The OECF target shown in Figure 16 that was manufactured to measure tone reproduction can be used, under certain circumstances, to measure noise over a wide range of input values. A special noise target (Figure 35) that also includes patches with frequency patterns has been developed by ANSI IT-10.

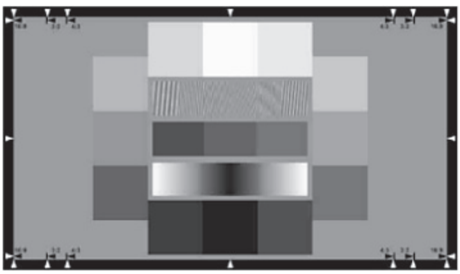


Figure 35. Target used for noise measurements (see ISO Test Charts, p. 45).

Color Reproduction

In addition to the image quality framework on the input side, color reproduction and tone reproduction in all areas of the image database were looked at more closely in the second phase of the project. This report will not go into detail in this area. The following shows a theoretical approach that IPI has been developing over recent months.

Because of its complexity, color reproduction (Figure 36) was beyond the scope of this project; there are, however, a few thoughts to be considered.[51-53]

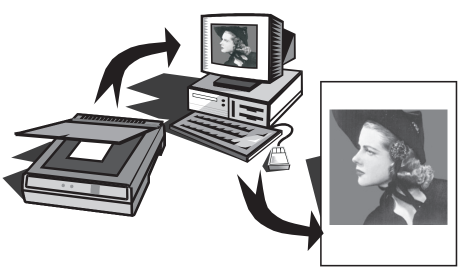


Figure 36. Matching original, soft copy on the monitor, and hard copy is the goal of color management.

Two basic types of image database can be defined, each needing different approaches to creation, access, and use of images. The first type of image database is the one containing large numbers of images, e.g., an image database for an insurance company, a government agency, or a historical society. In this case, the intent is to have in the database a good-quality image that is not necessarily colorimetrically true to the original. It is the information content of the image that is important. It is agreed upon from the beginning that the digital file in the image database will not be used to reconstruct the original photograph or scene.

The other type of image database will be built in environments where it is important that the digital image is a “replacement” of the original. Therefore, the digital data has to be captured and archived in such a manner that the original can be reconstructed.

Pictorial Rendering Intent

When targeting a wide user audience, computer platforms, color management systems, calibration procedures, color space conversions, or output devices cannot be mandated. Almost every institution has a different setup for access of the images. In addition, at the time of creation, it is usually not known what type of hardware and software are or will be available for access. Furthermore, one has to consider that the users of image databases are usually not trained in matters of digital imaging. However, they are visually sophisticated and are used to the quality they can get from conventional photographic images.

Nevertheless, decisions have to be made about spatial resolution, tone reproduction, and color space before images are digitized. In most cases, it will not be the goal to reproduce the physical properties of the original, but to reproduce its appearance under certain viewing conditions. Assumptions about the rendering device, color reproduction, and tone reproduction have to be made.

All original artwork cannot be treated equally. Different digitizing approaches have to be established according to the type, condition, and perceived values of the originals. Current scanning technology deals reasonably well with current film emulsions and formats, provided that they have been exposed and processed correctly. However, many collections of high artistic and/or historical value were captured on photographic material that not only isn’t available anymore, but also has deteriorated to some degree.

There are several rendering intents that apply while digitizing original artwork.

- **The photographic image is rendered.** In this case, the images are scanned with the intent to match the appearance of the original photographic image. The quality of the digital image can be evaluated by visually comparing the original to a reproduction on a calibrated display device with

Figure 37. Matching the appearance of the original photograph will be the prime goal in many archives databases.

Figure 38. An underexposed slide might be corrected during scanning to render the photographer's intent.

a similar contrast range. The assumption is made that the original photograph has been exposed and processed perfectly (Figure 37).

- **The photographer's intent is rendered.** There are many photographs with high content value that were not exposed or processed correctly. They can have a color cast, be over- or underexposed, or have the wrong contrast. In these cases, the photographer's intent, not the original photograph, needs to be rendered to achieve a pleasing reproduction. The scanner operator has to make decisions about tone and color reproduction by viewing the digitized image on a calibrated output device. This manual intervention determines the quality of the reproduction. Quality becomes highly dependent on the skill and experience of the operator (Figure 38).
- **The original appearance of the photograph is rendered.** Often, older color photographs are faded and no longer have sufficient visual color information to make accurate judgments about the original. Reconstructing these photographs requires special scanning and processing techniques.[54,55]
- **The original scene is rendered.** When photographic reproductions of original artwork are scanned, the original scene has to be rendered and the film characteristics have to be subtracted. However, this is only possible if a target is included on the film and the film characteristics and lighting conditions are known. It is therefore probably better to scan the original artwork.

With current scanning and color management technology, the first case, rendering the photographic image, can be automated if it is possible to match the dynamic range of the output to the original. All other cases need manual intervention, either in the initial scanning process or in subsequent image processing. Manual intervention is time-consuming and requires highly skilled operators. As a result, production costs remain high for high-quality, visually pleasing digital images. Better automated image processing tools need to be developed to analyze raw sensor data and translate it to pictorially pleasing digital reproductions on defined output devices.

Choosing a Color Space

The most important attribute of a color space in an archival environment is that it is well defined. Scanning for an image archive is different from scanning for commercial offset printing. When an image is scanned for archival purposes, the future use of the image is not known, nor are the technical options that will be available a few years from now. Will color profiles still be maintained or even used? An eight-bit-per-color scanning device output might be sufficient for visual representation on today's output devices, but it might not capture all the tonal subtleties of the original. Operator judgments regarding color and contrast cannot be reversed in a 24-bit RGB color system. Any output mapping different from the archived image's color space and gamma must be considered. On the other hand, saving raw scanner data of 12 or 16 bits per color with no tonal mapping can create problems for future output if the scanner characteristics are not well known and profiled.[56]

As an option, a transformation can be associated with the raw scanner data to define the pictorial intent that was chosen at the time of capture. However, there is currently no software available that allows one to define the rendering intent of the image in the scanner profile. Rendering intent is usually set during output mapping by the user. There is software available that allows the user to modify the scanner profile for individual images, and therefore to create "image profiles." That process is as work-intensive as regular image editing with the scanner or image processing software. It also assumes that the input profiles can and will be read by the operating system and application the image is used in, not just by current but also by future systems.

Archiving for each image both a raw sensor data file in high bit-depth and a calibrated RGB 24-bit file at high resolution is not an option for a lot of institutions, considering the number of digital images an archive can contain.

Because the output is not known at the time of archiving, it is best to stay as close as possible to the source, i.e., the scanning device. In addition, scanning devices should be spectrally well characterized, and the information should be readily available from the manufacturers.

INTERNATIONAL COLOR CONSORTIUM (ICC)

The ICC was established for the purpose of creating, promoting, and encouraging the standardization and evolution of an open, vendor-neutral, cross-platform color management system. ICC standards will be important for the color fidelity of image databases, since ICC profiles are being used in some projects in the field. Currently, the ICC defines a profile format that contains mapping information from input or output device color space to a PCS (profile connection space). How this mapping is achieved is vendor-specific. As a result, mixing profiles from different vendors for the same devices can result in different image reproduction. However, using profiles is only a temporary solution for archives. In the long term, other solutions are needed that are more open and that do not include any proprietary technology.

New Tools and Developments

Archiving 10- to 12-bit-per-channel standardized RGB color space would be optimal. Having to communicate only one color space (or profile) to the user's color management system would facilitate optimal rendering of all images across all platforms and devices. If the color space were standardized and universally recognized, the need to embed a profile into each image file would be eliminated. (Embedding profiles into each image file creates too great a data overhead when delivering preview files over the Internet.) There would also be only one profile that needs to be updated when color management specifications evolve in the future.

The sRGB color space proposed by Hewlett-Packard and Microsoft (or an extended version allowing the accommodation of an unlimited gamut and out-of-gamut colors) is a viable color space choice for access files. It is sufficiently large to accommodate most photographic reproduction intents. Since the first future access to any file will most probably be some kind of a monitor using an RGB color space, choosing to keep the access data in the currently defined sRGB is a valid solution. Images in sRGB will display reasonably well even on uncalibrated monitors. Higher bit-depth per channel would make it possible to communicate the predefined rendering intent for each image while leaving enough bit-depth for users to modify the image and to map to the intended output device. It would also give a safety factor to the archive file if future high-quality output devices require extensive mapping to as yet unknown color gamut and gamma. Also, colors that currently fall out of gamut could still be accounted for by leaving enough room on both ends of the values scale when defining black and white values. A standard way to deal with higher than eight-bit-per-channel image data across platforms and applications has to be developed.

The ultimate goal is a truly seamless, transparent work flow of images across platforms, devices, and, ultimately, time.

It has been encouraging to see the development of high-quality tools destined for digital image applications other than prepress. However, there is still a need for more integrated systems to achieve a truly seamless, transparent work flow of images across platforms, devices, and, ultimately, time. No one imaging technology manufacturer will ever be able to dictate to the end-user which imaging system to use. Additional standards will have to be developed to facilitate communication between imaging systems and to enable high-quality digital imaging for image database applications.

Monitor Viewing Conditions

ISO 3664 (Viewing Conditions—for Graphic Technology and Photography) requires the following:

- *The chromaticity of the white displayed on the monitor should approximate that of D65. The luminance level of the white displayed on the monitor shall be greater than 75 cd/m2 and should be greater than 100 cd/m2.*
- *When measured in any plane around the monitor or observer, the level of ambient illumination shall be less than 64 lux and should be less than 32 lux. The color temperature of the ambient illumination shall be less than or equal to that of the monitor white point.*
- *The area immediately surrounding the displayed image shall be neutral, preferably grey or black to minimize flare, and of approximately the same chromaticity as the white point of the monitor.*
- *The monitor shall be situated so there are no strongly colored areas (including clothing) directly in the field of view or which may cause reflections in the monitor screen. Ideally all walls, floors, and furniture in the field of view should be grey and free of any posters, notices, pictures, wording, or any other object which may affect the viewer's vision.*
- *All sources of glare should be avoided since they significantly degrade the quality of the image. The monitor shall be situated so that no illumination sources such as unshielded lamps or windows are directly in the field of view or are causing reflections from the surface of the monitor.*

Image Artifacts

In addition to the four parameters described above, it is important to check for image artifacts such as drop-out lines, banding, etc. These artifacts can be consistent from image to image. There is not much that can be done about these types of artifacts, since they are introduced by the sensor or the network connection between the sensor and the CPU.

Setting Up Imaging Systems

A common problem when using different computer systems or monitors in an environment is the difference between the images when viewed on the various systems. Systems need to be set up and calibrated carefully. More often than not this is not done properly, leading to various problems. For example, even if systems are actually being calibrated, measurements may not be taken correctly.

Monitor Calibration

In many digitization projects monitor calibration is an important consideration, not only when working with images but also when discussing the quality of scans with vendors over the telephone. If monitors are not properly calibrated, the two parties will not see the same image. To solve this potential problem, the National Archives, for example, have the same system setup for their quality control station as their vendor.

If the monitor is the defined output device, as it is for many projects, it needs to be calibrated to a specific white point and gamma. A monitor's gamma is a measure of the response curve of each of the red, green, and blue channels, from black to full intensity. Typical gamma values for color monitors range from 1.8 to 2.2. For PC systems the latter value is usually chosen; in Mac environments 1.8 is the gamma value that is widely used. The white point of a monitor is the color of white produced when all three color channels are at full intensity. It is specified as a color temperature measured in Kelvin (with images getting bluer as their color temperatures rise). Typical for this type of application is a setting to 6500° Kelvin.[57]

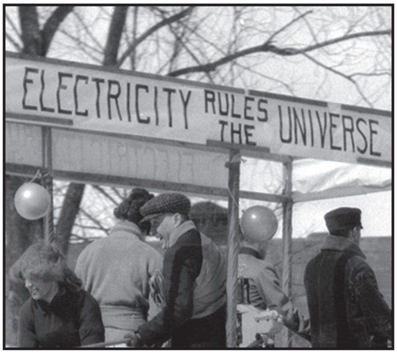
There exist various calibration methods and tools that differ widely in complexity. Some application programs incorporate basic monitor calibration. Furthermore, there exist specific calibration programs. Depending on the need of the user, they can be very sophisticated and incorporate devices like photometers and colorimeters.

The best way to view a monitor is under dim illumination that has a lower correlated color temperature than the monitor. This reduces veiling glare, increases the monitor dynamic range, and enables the human visual system to adapt to the monitor. This viewing condition results in the most aesthetically pleasing monitor images. Viewing originals and images on the screen side-by-side is more problematic, because in this case the observers are not allowed to adapt to each "environment" individually.

Once calibrated, the monitor should need re-calibration only when conditions change, or on a monthly basis. It is a good idea to put a piece of tape over the monitor's brightness and contrast controls after calibration and to maintain consistent lighting conditions.

A FEW POINTS TO REMEMBER

- *The area used for scanning needs to be big enough to accommodate preparation of:*
  Images
  Scanning
  Quality control.
- *Critical points to be checked after scanning:*
  Sharpness
  Correct file name
  Laterally reversed images.



Digital Master and Derivatives

It has been agreed upon in the preservation community that several files should be stored for every image to fulfill all requirements, mainly preservation and access. First, a so-called *archive file containing more than eight bits per channel should be stored. It should not be treated for any specific output and should be uncompressed or lossless compressed. From the archive file, various access files can be produced as needed. These might be based on a particular use that defines tone reproduction, and color reproduction, and pictorial interpretation.*

The highest quality file produced is referred to as the *digital master*. The quality level of the digital master will depend on the goals of the project, and in most cases its level of quality will be dictated by the project budget. From this digital master several derivatives can be produced. Usually up to five different quality levels will be produced (see, for example, www.nara.gov). Again, this depends on the project.

Quality and Process Control

The best approach to digital image quality control includes, on one hand, subjective visual inspection and, on the other hand, objective measurements performed in software on the digital files themselves. Efforts should be made to standardize the procedures and equipment for subjective evaluations by means of monitor and printer calibration. For objective image quality measurement, software should be available which is designed to locate and evaluate specific targets and then report numbers or graphs describing key image quality parameters. Such software should ideally be a plug-in to a full-featured image browser so that all aspects of the image file (header info, index, and tracking data, etc.) can be reviewed at one time. Some software components already exist, others are currently being developed.

A key point is that targets and the software to evaluate them are not just for checking systems—they serve to guarantee the long-term usefulness of the digital files and to protect the investments of the institution.

Since some of the targets and software described here are not yet commercially available, it will still be some time before consistent quality control can be set up. Nevertheless, these tools will be available soon, and their inclusion in future work flow is recommended.

Sample materials representative of the photographs in a collection to be scanned should always be included in the system tests. It is crucial that sample materials are a true representation of the collection. Taking these sample images through the whole processing chain will help to ascertain whether a particular quality level can be reached. Depending on the goals of the digitization project, this process may include working with outside vendors, printers, and the like.

Benchmarking Scanner Systems

Standards are currently being developed for benchmarking scanning systems. In most cases the test requirements will far exceed the necessary performance for actual scanning. Benchmarking systems will help to compare different hardware, give more adequate information than that which is currently available from the manufacturers, and hopefully lead to a better understanding of the whole process.

Reproduction Qualities and Characteristics of the Digital Master and Derivatives

The reproduction qualities of digital images will have to be monitored during and controlled after their production. Hence, a quality-control step needs to be incorporated into every production step. This process serves to ensure that images actually reach the quality margins that have been set for the various parameters.

Functional Qualities and Characteristics of the Digital Master and Derivatives

Besides tests for reproduction quality, additional tests are needed to make sure that the functionality of the digital master is inherent in the digital file. These include looking at file formats and performance, for example, always keeping in mind the longevity of the data.

IPI recommends the use of standard file formats such as TIFF, which is thoroughly published. This ensures independence from proprietary formats that might one day be discontinued. New file formats like TIFF/EP,[32] or something similar, might be more widely used in the future. TIFF/EP is based on TIFF 6.0 and uses a large number of tags to store additional information. JPEG2000 is another standard that should be considered.

> METADATA:
> "DATA ABOUT THE DATA"
>
> - *Discovery metadata for finding.*
> - *Administrative metadata for viewing and monitoring.*
> - *Structural metadata for navigation.*
> - *Rights-management metadata for controlling access.*

Documentation of the Imaging Process—Technical Metadata (Subcategory of Administrative Metadata)

To be able to work with images across platforms, as well as over time, it is important that the imaging process is well documented and that the information is kept with every file. The National Information Standards Organization has published a standard called *Technical Metadata for Digital Still Images*.[58] It represents a comprehensive list of technical metadata elements required to manage digital image collections.

Image Processing

Image quality is affected by the sequence of applying different image processing steps.[59] It is important to be aware of the effects of different processing algorithms (e.g., resampling, sharpening and noise reduction, tone and color correction, defect elimination, and compression). It also has to be kept in mind that the future use of the images is not clear. Ideally, all image processing should be delayed until the time an image is actually used and image rendering and output characteristics are known. This would require the data to be stored with a bit-depth of more than eight bits per channel. Unfortunately, most work-flow solutions currently available do not allow this.

Processing for Monitor Viewing

- *A linear distribution of the tones in a digital image compared to the density values of the original offers greater potential for future functionality, but images need to be adjusted before being viewed on a monitor.*
- *Adjusting master files for monitor representation provides better viewing fidelity but means giving up certain processing possibilities in the future.*

Data Compression

- *For archiving: uncompressed*
- *For use: lossy*

Processing for Archiving

Image data is best stored as raw capture data. Subsequent processing of this data can only reduce the information content, and there is always the possibility that better input processing algorithms will become available further on. The archived image data should therefore be the raw data, and, when possible, the associated information required for processing, such as sensor characteristics, illumination, and linearization data.

Processing for Access

Processing for viewing is a type of output processing applied to produce images of good viewing quality. It is possible to design viewer software that can take image files that have undergone input processing and process them for output on a monitor.

Data Compression

Advances in image-data compression and storage-media development have helped to reduce the concern about storage space for large data files. Nevertheless, image compression in an archival environment has to be evaluated very carefully. Because in this case the future use of a digital image is not yet determined, one copy of every image should be left uncompressed. Current lossless compression schemes do not bring too much in terms of reduction of storage space. Also, it should be remembered that the loss of one crucial bit could mean the loss of all of the file information, even in the case of lossless compression.

New compression schemes, like wavelets, which do not produce the well-known artifacts that JPEG compressed files show, are still not readily available.

Two of the most widely used compression schemes are briefly described below.[60]

Lossless and Visually Lossless Compression
All good compression schemes sacrifice the least information possible in achieving a reduced file size. Lossless compression makes it possible to exactly reproduce the original image file from a compressed file. Lossless compression differs from visually lossless compression (compression where the artifacts are not visible). Although the human visual system provides guidelines for designing visually

lossless compression schemes, ultimately the visibility of compression artifacts depends on the output.

- **LZW (Lossless Compression).** LZW (Lempel-Ziv-Welch) is a type of entropy-based encoding. It belongs to a class of lossless compression that is performed on a digital image file to produce a smaller file which nevertheless contains all the information of the original file. Currently, the most common schemes are those based on Huffman encoding and the proprietary LZW compression (used for TIFF files in Adobe Photoshop).

  Unfortunately, the granular structure of film hinders effective entropy-based encoding. The film grain imposes a fine random noise pattern on the image that does not compress well. There is currently no effective lossless solution to this problem.

- **Photo CD (Visually Lossless Compression).** The Photo CD compression scheme utilizes both frequency and color compression in an attempt to produce visually lossless compression.

Figure 39. Even lightly compressed JPEG (4:1/5:1) can show some compression artifacts. For compression, the image is divided into 8 x 8 pixel blocks; these blocks are a major source of visible artifacts. Therefore, the highest-quality master file should be archived using a lossless compression algorithm.

Lossy Compression

JPEG stands for Joint Photographic Expert Group, which is the group responsible for the development of the compression approach named after it. JPEG is one type of lossy compression with a number of user-selectable options (Figure 39).

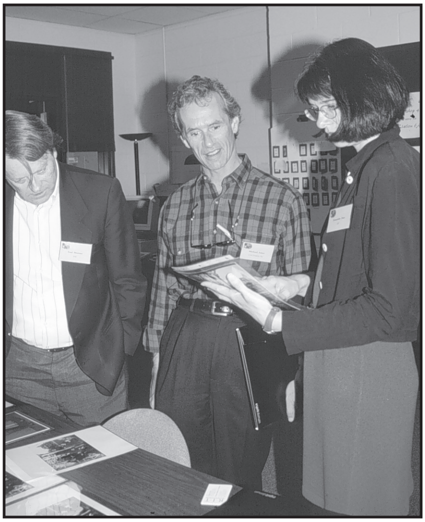
The advantages of JPEG compression are its user selectability to ensure visually lossless compression, high compression ratio, good computational efficiency, and good film grain suppression characteristics. Future development proposed for the JPEG standard allow for tiling extensions, meaning that multiple-resolution versions of an image can be stored within the same file (similar to the concept behind the Photo CD files).

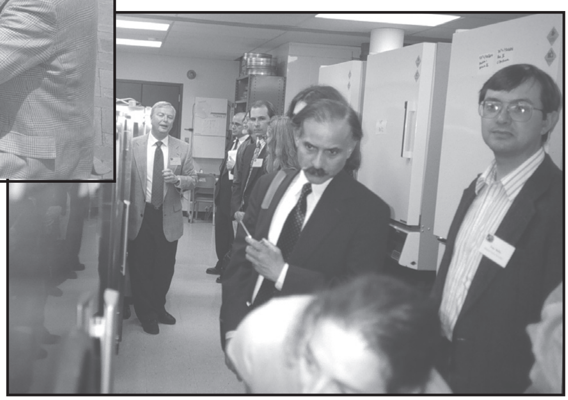
The concern that repeated JPEG compression causes deterioration of image quality is valid.[61] Consequently, all image processing should occur before the file is compressed, and the image should only be saved once using JPEG.

THE CONFERENCE

The outcome of the IPI study was presented in a three-day conference at RIT in June, 1997. During the course of the project we had the opportunity to build a network with a wide variety of individuals working in the field of digitization. The concept for the conference was to bring together experts from different backgrounds and to try to determine whether a dialogue was possible and desired by those in the field. Putting together the program was a very interesting process, and we were pleasantly surprised that all the speakers immediately agreed to come. We took this as an indication that the chosen approach was appreciated in the field.

The conference, entitled "Digitizing Photographic Collections—Where Are We Now? What Does The Future Hold?" was held in the new CIMS building on the RIT campus. Over 120 people attended, a third of whom came from outside the US. The program was well received by both speakers and attendees. The topics presented during the three-day event are listed on page 39.





DIGITIZING PHOTOGRAPHIC COLLECTIONS

June 7-9, 1997

INTRODUCTION
Digitizing Photographic Collections: the Big Picture—*James Reilly and Franziska Frey, IPI*
Funding Possibilities—*Charles Kolb, NEH*

IMAGE QUALITY
Introduction to Digital Image Quality and a Look at Tools to Control It—*James Reilly and Franziska Frey, IPI*

PROJECTS
Digitally Archiving Glass Plate Negatives—*Vienna Wilson, University of Virginia*
Adventures in Reformatting: A Hybrid Approach—*Connie McCabe, Photo Preservation Services, Inc.*
Digital Archive Solution for the US Holocaust Museum—*Holly Frey, Applied Graphic Technologies*

IMAGE INTERCHANGE AND MIGRATION—NEEDS AND TOOLS
FlashPix Image File Format—*Chris Hauf, Kodak*
Determining Conversion Requirements for Special Collections Material—*Anne Kenney, Cornell University*
The Museum Educational Site Licensing Project and Issues of Image Interchange and Metadata—*Howard Besser, UC Berkeley*

SHARING EXPERIENCES
Imaging Systems for the Creation of a Large Digital Archive—*Sabine Süsstrunk, Corbis Corp.*
Modern Times at the Picture Factory—*Carl Fleischhauer and Phil Michel, Library of Congress*
Technical Overview of the National Archives' Electronic Access Project—*Steve Puglia, National Archives*

THE TECHNOLOGY—A CLOSER LOOK AT SOME DETAILS
Visible Human Images: Compression Techniques—*George Thoma, National Library of Medicine*
Scanning Technology: Now and the Future—*Paul Norder, Xerox Corporation*
Digital Color Printing Systems—*Frank Cost, RIT*

NATIONAL AND INTERNATIONAL TRENDS IN IMAGE DATABASE PROJECTS
Filling the Frame: Selected International Efforts in Photographic Digitization—*Nancy Elkington, Research Libraries Group*
Digital Image Collections: Issues and Practice—*Michael Ester, Luna Imaging*
Digitizing Collections of Cultural Materials for Digital Libraries: Some Experiences—*Fred Mintzer, IBM*

DIGITIZE TO PRESERVE
Imaging Investments: How to Negotiate for Quality and How to Measure It—*Steve Chapman, Harvard University*
Preservation in the Digital World—*Paul Conway, Yale University*
Meeting Preservation Priorities While Digitizing a Photographic Collection—*Paul Messier, Boston Art Conservation*

IMAGE QUALITY
Project Presentation: Images of African-Americans in 19-Century Illustrations—*Anthony Troncale, New York Public Library*

PANEL DISCUSSION
Technical Issues and Foundations for Standards

CONCLUSIONS

With the advent of digital imaging, new approaches to preservation strategies are needed for photographic collections in libraries and archives. The preservation community must be involved in designing these strategies. The practices that are being developed and used influence the development of the field as a whole. A great deal of expertise has been accumulated through various projects.

However, there still remain questions on "how-to" that have to be solved, the sooner the better. Since budgets are limited, most of the scanning probably will be (and should be) done only once. If project outcomes are not satisfactory, it will not only be disappointing for the participating team, it will also be considerably harder to get funding for a second project. We see more development needed in incorporating quality control into a work flow, solving color issues, and creating the right metadata to allow the files to be transferred to future systems.

The more deeply we became involved with image quality, the more we saw that the imaging process cannot be viewed in a linear fashion. All the components are interdependent and therefore must be viewed as a whole. Nevertheless, understanding the components singly is the basis for understanding how they influence each other.

The many advantages of the emerging digital technologies for photographic collections are obvious, but there is still a long way to go. The technology is still young and in constant flux. Most importantly, communication among all participating parties must be improved. Due to the fast-changing and complex imaging technologies involved, collection managers need to work together with engineers and imaging scientists, who often lack collection-related knowledge. Each side must be willing to learn the special needs of the other. The conference that was organized within this project demonstrated this. This is perhaps the project's most encouraging outcome for the preservation community.

Finally, it must be remembered that imaging is about images. Visual sophistication is needed to successfully master a digital imaging project—and this is clearly plentiful in the world of museums, archives, and libraries.

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Selected Internet Resources

Countless resources and references can be found on the Internet. The following list is a selection to start with. (World Wide Web URLs confirmed as of February 1, 2006.)

Art Spectral Imaging
art-si.org

Arts and Humanities Data Service
www.ahds.ac.uk

Council on Library and Information Resources
www.clir.org

Dublin Core
dublincore.org

Electronic Still Picture Imaging
www.i3a.org/it10.html

European Commission on Preservation and Access
www.knaw.nl/ecpa

The International Color Consortium (ICC)
www.color.org

ISO Standards
webstore/ansi.org/ansidocstore/iso.asp?

ISO Standards Tools
www.i3a.org/pdf/resource_order_form.pdf

ISO Test Charts
www.i3a.org/iso_test_charts.html

Library of Congress/American Memory—Technical Information
memory.loc.gov/ammem/about/techIn.html

MCN—Museum Computer Network
www.mcn.edu

The National Archives
www.archives.gov

National Media Lab
www.nml.org

RLG DigiNews
www.rlg.org/preserv/diginews

The Visual Resources Association
www.vraweb.org

THE IMAGE PERMANENCE INSTITUTE

The Image Permanence Institute is an academic research laboratory located on the campus of the Rochester Institute of Technology in Rochester, New York. Since its founding in 1985, IPI's mission has been research for the advancement of the permanence and preservation of imaging media and information resources. IPI is cosponsored by RIT and the Society for Imaging Science and Technology.

Research at IPI deals primarily with preservation of images and recorded information. IPI has achieved success with projects involving enclosure quality, silver image stability, decomposition of cellulosic plastic film supports, color dye fading, paper deterioration due to air pollutants, magnetic tape preservation, and environmental assessment and control. IPI is known for its accelerated-aging studies of photographic materials including acetate, nitrate, and polyester films, color dyes, and gelatin. These studies have underscored the strong role that environment plays in all modes of decay and the importance of managing storage for preservation.

Among the products and services developed by IPI are the Photographic Activity Test, a worldwide standard (ISO Standard 18916) for archival quality in photographic enclosures; A-D Strips, a test for vinegar syndrome in acetate film; the Preservation Environment Monitor®, a unique electronic data logger designed specifically for preservation use; Climate Notebook® environmental analysis software; and the cost-effective Environmental Analysis Service for libraries, archives, and museums.

IPI serves the preservation community not only through its research, products, and services, but also as a ready source of technical information. In addition, IPI provides technical and administrative support for the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) in the area of permanence and care of imaging media, including photographic materials, tape, and optical discs.