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Imaging Methods and Quantitative Measurements for the Characterization of Digitally Printed Materials

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Over the last five years, researchers at the Image Permanence Institute at the Rochester Institute of Technology have been developing an imaging strategy and a set of quantitative measurements that can be used to characterize modern digital print materials (both images and documents). While the goal of the project has ultimately been to enable personnel in cultural heritage institutions to identify their collection materials, the approaches should also be helpful to the field of forensic document examination. The imaging methods include varying the angle of lighting as well as the level of magnification. Structures such as surface gloss and texture as well as dot morphology and pattern can be assessed and compared to known print types. Additional, unique traits such as colorant bronzing, differential gloss, anti-block layers, etc. can also be used to narrow down the identification of particular print examples. This paper will describe the main approaches used for both imaging and quantitative measurement of print samples along with descriptions of where support tools can be found online.

Introduction

The Image Permanence Institute (IPI) is a university-based, non-profit organization dedicated to providing science-based best practices for the care of cultural heritage collections in museums, archives, and libraries. For the last five years, the study of the permanence and preservation of modern, digitally printed materials has been a major focus. One aspect of this research has been the development of a methodology by which collection care professionals in these institutions can identify the specific types of modern prints in their collections. Currently, most institutional personnel do not know how to identify these materials, either to segregate them from traditional print types or to differentiate them from each other. This is critical for them as each print type has its own vulnerabilities to storage, use, and display and may need a unique preservation strategy.

Similarities between the work of cultural heritage and that of forensic document examination are easily seen as both groups seek to accurately identify printed materials. Of course there may also be differences, as forensics analysts may wish to identify a print to the level of specific printer, ink and paper used to create it (e.g. Epson C60 printer using Rhinotek black ink on Staples Bright White Inkjet Paper), while museums, libraries and archives may only seek to develop identification techniques for more generic categories (e.g. dye inkjet on plain office paper) that lead to the proper long-term care of the material. Also, while there are a variety of modern printing technologies and an even greater number of substrates to print on, this current work focuses only on the most common digital print types - inkjet, electrophotography, and dye sublimation. Despite the differences, it is hoped that the similarities can lead to a synergy between the two fields enhancing the outcomes of digital print identification research for both.

Since the beginning of this research, the goal has been to develop a reliable methodology by which collection care personnel can accurately identify the various types of digital print types in their institutions. The first phase of the study (2007 to 2010), resulted in creation of IPI's online tool, now posted on the Digital Print Preservation Portal (DP3) website. This tool can readily teach users how to identify prints to the topmost technology levels (inkjet, dye sublimation, and electrophotography), as well as how to differentiate prints made with the digital technologies from common traditional print types. However, the online tool is not yet able to teach identification of the various sub-categories of print types (e.g. dye inkjet on presentation paper vs. pigment inkjet on fine art paper) that have their own unique permanence characteristics and will need separate preservation approaches to maximize usable life.

Since the beginning of the second phase of the study, it has been discovered that meeting the new goal of deepening the identification techniques to include the sub-categories will not be simple. Part of the problem has been that digital print materials have historically been described and categorized by an existing set of terminology passed on from the manufacturers and their marketing departments. Many print materials have attributes from multiple existing categories, and others don't match any, so new categories may need to be created. In other words the field is in the precarious position of not having an accurate terminology for the materials under study.

To address this problem, a slightly different approach has been taken. Instead of cataloging known differentiating attributes for the existing categories, the intent is to more fully characterize the digital print materials in use and develop a new taxonomy that will match both what can be measured and observed for these objects. This new approach can be likened to that of the lepidopterist that collects hundreds of butterfly samples and then systematically studies the collection for patterns and groupings. In this case, patterns such as number of printing colors, dot morphology, surface reflectivity, etc. are being investigated. This investigation, therefore, needed to start with the development of a standardized set of imaging strategies and measurements which could quantify and/or qualify the physical and optical/visual qualities of the materials. Discussion of these strategies and measurements is the purpose of this paper.

Addressing the above problem should help both fields in another way. Currently, the terminology being used in cultural heritage institutions to create print descriptions is diverse and inconsistent. These descriptions have been further complicated by art market forces. For example, previously a fine art print might have been called a *giclée* whereas today that term is usually rejected by artists in favor of something more like *archival pigment print*. This is not really much of an improvement, as it says nothing about the printer technology or paper used, just the colorant and the intent of the print to be long-lasting. In reality, many terms are used, or in some cases not used, to describe these modern materials. Characterization studies, such as the current work, should go far towards helping develop a better, more consistent way of describing these objects.

Methods

The imaging techniques described below are certainly not new but their application to the problem of print identification has not been systematically studied for cultural heritage institutions. In many ways this project owes its origins to James Reilly's seminal book *Care and Identification of Nineteenth Century Prints,* which utilized a system of micrographs of eyes from different photograph types to highlight their differences (or similarities). These could then be used to segregate the 19th century photo materials into broad categories such as albumen, cyanotype, and platinum print.

Additionally, in 2007, IPI research scientist Ryan Boatright began experimenting with imaging methods to capture print characteristics that could be displayed on the web and used by artists and print makers to select papers that would match their intended applications. Micrographs of eyes from various print-types were again chosen as the focal point for discussion of image and paper attributes. Under the guidance of IPI's director James Reilly, Boatright and several other IPI staff have expanded upon that work to create the Graphics Atlas which utilizes image sets and text descriptions to describe printing processes spanning the entire history of mechanical printing from wood block to inkjet. The Graphics Atlas website was then launched in 2010.

The techniques were taken a step further when the IPI digital print research team launched the Digital Print Preservation Portal's online digital print identification tool. This new site differed from Graphics Atlas in that it focused solely on digitally printed materials. The imaging and measurement techniques addressed in this paper are those currently being used in IPI's digital print research.

Imaging Techniques

The imaging techniques are based mostly on variations in light type and angle as well as different levels of magnification. The lighting techniques and variations in magnification can also

(a) Full size (b) 10x (Macro-lens/copy stand) (c) 50x (Microscope)

Figure 1. Variations in magnification.

be combined for even further variations in how prints can be examined visually. Additionally, images of print cross sections can be obtained to illustrate the various characteristics of paper design and manufacture.

Magnification

Varying the magnification can illustrate key attributes of prints. For example, high magnification would not show differential gloss effectively, so imaging of the entire object is necessary. Other attributes such as image structure require magnification through a macro lens on a camera or through a microscope. The first image in Figure 1 is of the entire print and shows the pictorial content. The next image is at a higher magnification (10x) where a rosette pattern appears (the circular shapes). Rosette patterns are a characteristic of a half-tone imaging (as opposed to continuous tone) with an amplitude modulated screen (AM screening). Half-tone screen patterns can also be helpful when differentiating certain print types but is not within the scope of this paper. Finally, the highest magnification (50x) shows the individual dots that form the image. The dots are distinct and fairly smooth edged. Each of these images provides clues to the type of printing device used – which is specifically an *HP Indigo print* or more generically a *liquid-toner electrophotographic print on glossy magazine stock*.

Lighting

A variety of lighting techniques can be used to illustrate characteristics of digital prints. Lighting is primarily used to show image qualities (such as color and image structure) or surface qualities (such as sheen and texture). Lighting of samples can be done axial to the camera lens (perpendicular to the image surface), at a 45° angle (using either visible or UV light), or raking (near zero degrees to the print plane). No single lighting system can illuminate all traits of a print.

In 45° lighting, the source is at angle of 45° to both the print plane and the lens axis. This is the best angle of illumination to show the print's image attributes (e.g. colors, image struc-

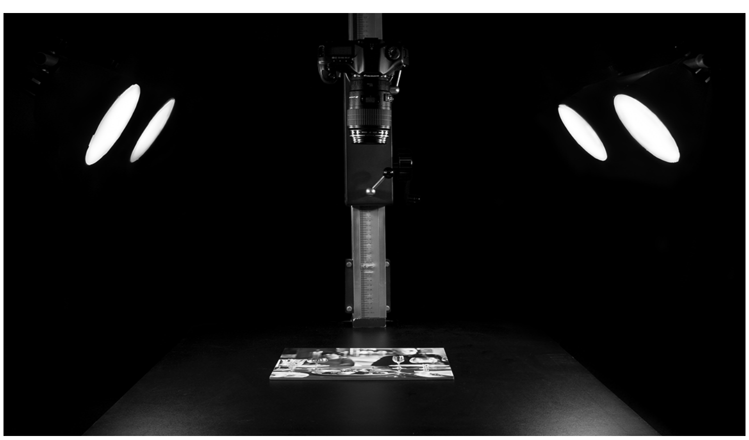
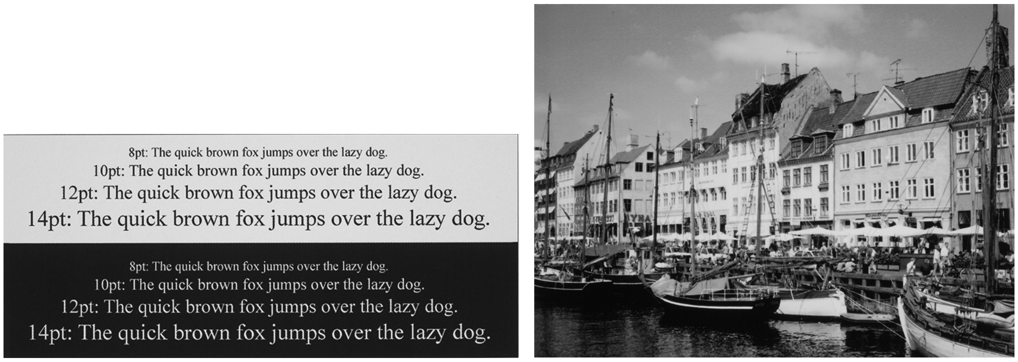


Figure 2. 45° lighting camera set-up.



(a) Text (b) Photograph

Figure 3. Examples of 45° lighting used to image text and a photograph.

ture, etc.) as specular reflection or shadows from surface topography will not appear in the image. A simple copy stand from a photographic equipment supplier is all that is needed (Figure 2). Examples of a photograph and printed text are shown in Figure 3.

In axial lighting, the source is on the same axis as the lens and perpendicular to the print being imaged. As a result of the angle of reflection being equal to the angle of illumination, very glossy samples will show high specular reflectance while matte samples will show diffuse reflectance. This type of lighting is very useful to show the sheen or gloss of a surface. It is not possible to actually put the light source in line with the lens as it would block the lens, so a 50% transmittance - 50% reflectance plate beam splitter (half-silvered mirror) is placed at a 45° angle between the lens and the print being imaged (see Figure 4 below). A fiber optic light stationed to the side of the mirror is aimed at a spot directly in line between the lens and the print. This reflected light puts the illumination in line with the lens. The camera can then photograph the print through the partially transparent mirror, though a longer exposure time is needed compared to photographing the print without the mirror in the way. In Figure 5, the glossy photo shows a bright spot in the center because most of the axial light is reflected directly back into the lens. The rough surface of the matte photo diffuses the light evenly so the bright spot does not appear.

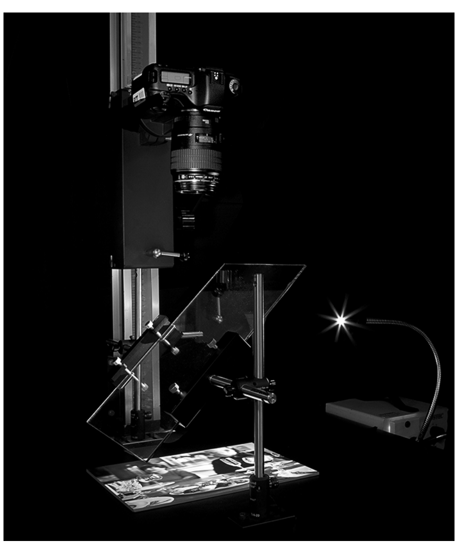


Figure 4. Axial lighting camera set-up.

In raking lighting, the illumination source is nearly parallel to the print plane and nearly 90° to the lens axis (Figure 6). This is highly suited to showing texture on print surfaces. Any surface feature that elevates from the print plane (such as paper fibers) will be brightly illuminated on the side proximal to the light source and in shadow on the opposite side. It is this type of lighting that shows craters on the moon as light from the sun rakes the moon's surface causing elevated features (e.g. crater rims) on the sun's side to appear light and on the opposite side, such as within the crater, to appear dark. Raking light is best used to show variations in texture on matte surface prints.

The images in Figure 7 show the effects of raking lighting on different digitally printed photographs. The image on the left shows a picture on plain office paper which has a texture to its surface imparted by the paper's fibers. The image on the right shows a picture printed on glossy photo paper. This print shows no texture as the paper is coated with both a thin layer of white-pigmented

(a) Glossy photo (b) Matte photo

Figure 5. Effect of axial light on surface sheen.

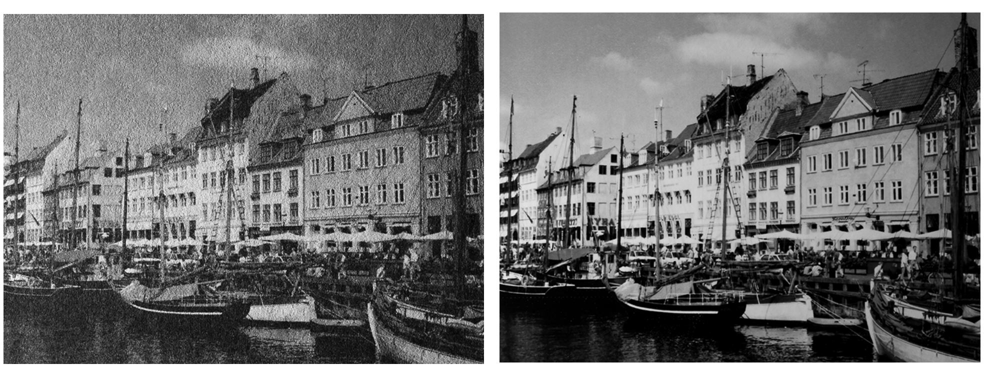
Figure 6. Raking lighting camera set-up.

polyethylene and an ink receiver layer made of tightly packed mineral particles.

UV lighting can be used to reveal optical brightening agents (OBAs) in prints. OBAs are dyes that convert non-visible, short wavelength (UV) energy into visible light (usually in the blue region). This has the effect of making the print look whiter and brighter. The OBAs can be included in print papers in different ways. Sometimes it is added to a whitening layer just under the printing surface. Sometimes OBA is added throughout the entire paper base during manufacture. Sometimes it is added to the front, the back, or both sides of the print. Figure 8 shows a copy stand with UV light sources replacing the 45° angle lighting from earlier. Note that the UV lamps do emit some violet light from the visible spectrum which helps with positioning the sample under the camera. Figure 9 shows two photographs imaged with visible light and Figure 10 shows the same two photographs imaged with UV light. The one of the right shows clear fluorescing under UV.

Mixed Magnification and Lighting

The different lighting strategies above can also be applied to images created in the microscope, potentially giving even more visual information than when photographed at full size alone. In the earlier section describing variation in magnifica-



(a) Inkjet on plain office paper (b) Inkjet on glossy photo paper

Figure 7. Raking lighting.

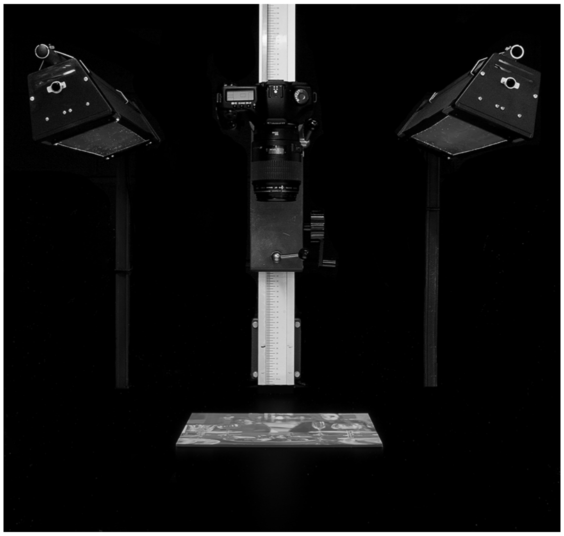


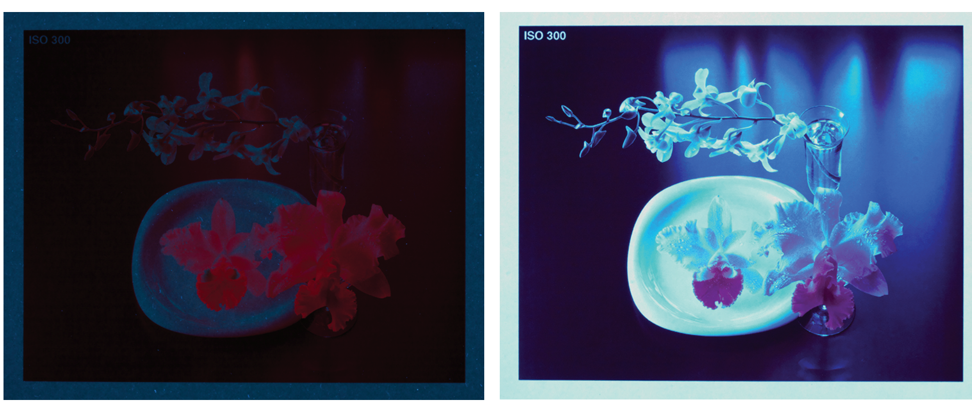
Figure 8. UV lighting camera set-up.

tion, all of the example images were created using 45° lighting to illuminate just image qualities and not aspects of print surface. Using axial and raking lighting in the microscope can provide additional information regarding print type and characteristics. Figure 11 shows micrographs of pigment and dye inkjet photos created using the same type (but not brand) of glossy inkjet photo paper. The image-forming dots in the pigment inkjet print protrude above the surface of the paper, creating interference colors. The dye inks, however, are fully absorbed into the paper's ink receiver layer, leaving no dot pattern at the surface. Axial illumination in the compound microscope is accomplished by aligning the axes of the analyzer and the polarizer filters within the microscope.

Figure 12 shows the effects of raking light on magnified images of documents. The image on the left is of an inkjet print on plain paper. The

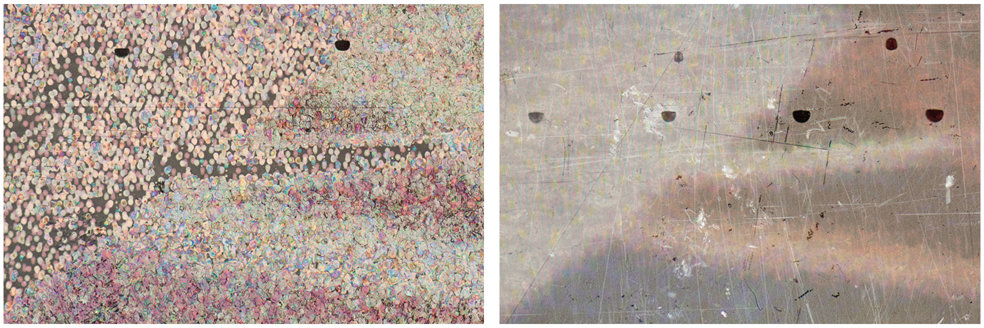
(a) Print without OBA (b) Print with OBA

Figure 9. Prints in visible light.



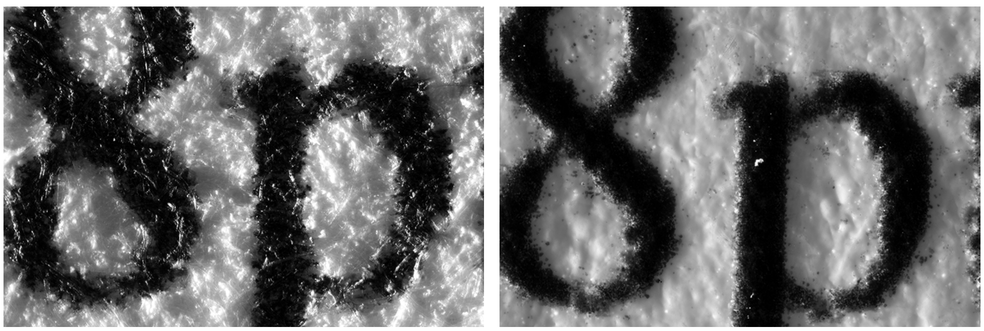
(a) Print without OBA (b) Print with OBA

Figure 10. Prints in UV light.



(a) Pigment inkjet photo (b) Dye inkjet photo

Figure 11. Axial plus 50x magnification.



(a) Inkjet document (b) Electrophotographic document

Figure 12. Raking plus 50x magnification.

raking lighting highlights the rough texture of the paper surface. The image on the right is of an electrophotographic print on a coated paper. Here the paper fibers are invisible and the toner, being unable to penetrate the paper surface, is raised above the paper surface creating a topography.

Cross sections

More can be learned about the structure and characteristics of a print material by looking beyond just its surface. Many print materials are made of several material layers, each contributing to the look, feel, and performance of the media. For example, many imaging papers are resin-coated. This is a paper type designed to look and feel like traditional color photographs. It consists of paper with a clear layer of polyethylene on the back and a white-pigmented layer of polyethylene on the front (the white pigment makes the image look bright). The colorant receiver layer is coated on top of the white-pigmented polyethylene layer. Using cross sectional imaging, it is possible to show the various layers that make up a print.

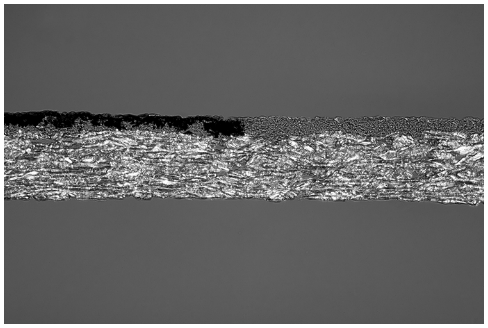
To prepare a cross-section, a 18-20 micron sliver of the material is cut on a microtome and then laid on its side under the microscope. The sliver is usually cut from an area of the print that includes both an unprinted area and a printed area. Figure 13 shows two inkjet papers with dramatically different constructions. The image on the left is from a typical high-end artist paper, while the second is a common type of inkjet photo paper. The ink receiver layer on the left is directly on the surface of the paper, while on the right the ink receiver layer is on top of the white-pigmented polyethylene coating.

Cross sections can also be illuminated with UV light, which is especially useful in finding exactly which layer in the print includes the OBAs compared to other prints. Figure 14 shows two different locations of OBAs; the sample on the left only has OBAs in the top layers of the print while the sample on the right shows OBAs dispersed throughout the paper.

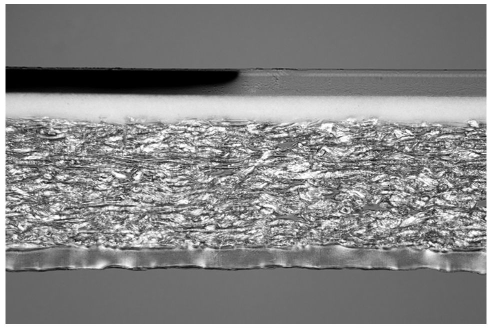
Measurement Techniques

Quantitative Measurements

In addition to the imaging techniques, a variety of quantitative measurements on prints can be

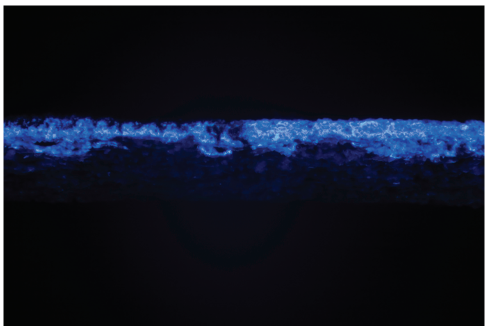


(a) Inkjet on fine art paper

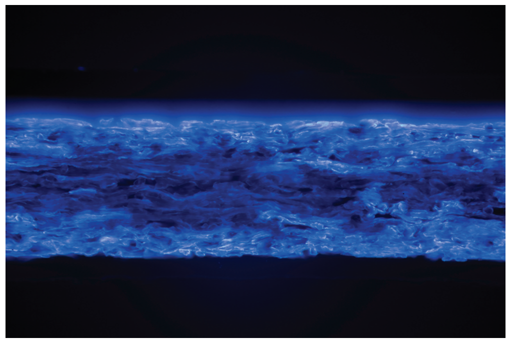


(b) Inkjet on porous photo-paper

Figure 13. Cross sections of inkjet photos.



(a) OBA in top coating



(b) OBA throughout

Figure 14. Different OBA patterns in cross section.

made. Some of these can be performed with simple visual inspection (such as counting the number of colorants used) and others by instrument (such as paper thickness). Other factors, such as presence of optical brighteners, can be done qualitatively by viewing the print under a UV source or quantitatively through the use of a spectrophotometer. The quantitative measurements currently being explored in this project are listed below (Table 1). Others may be added in the future. While not used on the IPI websites to teach print identification, these measurements can be very helpful in the characterization process.

Table 2 below shows a quantitative comparison of three different inkjet photographs. Gloss is measured in gloss units and at an angle dependent on a preliminary reading at 60°. From that reading a determination of whether a print is high gloss (above 70 gloss units), semi-gloss (between 10 and 70 gloss units), or matte (below 10 gloss units) can be made. It is important to know that manufacturers often market their print products using terms that do not match this approach. For example, most (if not all) traditional color photographs labeled as matte are technically semi-gloss. A large difference between the gloss of the paper and the gloss of the printed area is called differential gloss and is sometimes apparent when viewing the print under specular light. Sometimes the printed area is glossier than the

Property	***Measurement***
Number of colors	Count
Paper thickness	Thousandths of inches
Paper color	CIELab
Gloss (surface reflectivity)	Gloss units
Presence of OBA	Spectral reflectance
Print dimensions	Inches

Table 1. Quantitative assessments.

	Print 1	*Print 2*	*Print 3*
Printer technology	Inkjet	Inkjet	Inkjet
Photo or document	Photo	Photo	Photo
Number of printer colors	9	4	9
Optical brighteners	Yes	Yes	Yes
Measured gloss (printed area)	3.4	3.4	40.0
Measured gloss (paper only)	2.9	2.9	16.5
Determined surface	Matte	Matte	Semi-gloss
Caliper	.0112″	.0112″	.0147″
L* (paper only)	97	97	98
a* (paper only)	1	1	2
b* (paper only)	1	1	-4

Table 2. Quantitative comparison of print samples.

paper (such as for many laser prints on plain paper), and other times the paper is glossier than the printed areas (such as for some pigment inkjet-printed glossy photos). Each column in the table below starts with the printer technology (inkjet, electrophotography, etc.) followed by the object type (photo, document, etc.)

The inkjet Prints 1 and 2 are near identical because they were made using the same printer paper (Figure 15). They are both inkjet but the type of colorant is different. This can be distinguished mainly because the pigment printer could use up to nine colors while the dye printer only used four. Prints 1 and 3 actually used the same printer, but different papers that could easily be differentiated by their surface sheens (semi-gloss vs. matte), paper tints (CIElab measurements), and thicknesses. Also note the difference between the paper only and printed area gloss measurements for Print 3. This indicates that the print would show differential gloss. Below are full-sized images of the prints showing their visual similarity. The measurements clearly helped define them as separate objects.

Qualitative Assessments

In addition to the imaging techniques and quantitative measurements, there are a variety of qualitative assessments which can aid in print type identification. These are not currently being used in this study but are worth mentioning here. More information on these and others can be found in Martin Jürgens' book *The Digital Print: Identification and Preservation*.

- Bronzing
- Verso printing
- Satellites (spots of colorants outside of image forming dots)
- Screen patterns

Comments on Print Deterioration

It is important to note that many of the attributes discussed above can change within a given print over time, making comparisons with other prints more difficult. The gloss of many print types can be diminished due to exposure to air pollution, humidity or water, or even light. Additionally,

(a) Print 1 (b) Print 2 (c) Print 3

Figure 15. Example prints for quantitative assessment.

color can change if a paper begins to yellow or if one or more of the colorants begins to fade. It will still likely be possible to match a specific print to a broad print type category for even severely degraded prints; however, matching a specific degraded print to an identical but undegraded print might be more difficult.

Results

The new set of imaging techniques has led to better ways to illustrate the materials and educate various groups on the characteristics of the different digital print types. The major outcomes of this research to date are the following:

- The Digital Print Preservation Portal's online identification tool (www.DP3Project.org);
- Graphics Atlas (www.graphicsatlas.com); and
- Illustrations for educational workshops.

Of major importance has been the creation of the Digital Print Preservation Portal's online identification tool for the most common digital print materials – inkjet, dye sublimation, and electrophotography. In addition to the digital process are examples of traditional printing – silver-halide photography and offset lithography – to help users segregate the new process from the older. The website also contains supplemental materials that include explanations of the technologies and materials used in digital printing, descriptions of deterioration manifestations and mechanisms, and additional supportive information. Figure 16 below shows the front page of the online identification tool. Note that two materials can be studied side by side simultaneously to enable the user to become familiar with differentiating features. Use of this website is free to the public.

The Graphics Atlas website is another significant outcome of the development of the imaging techniques. Graphics Atlas has a wider variety of print types to explore than the Digital Print Preservation Portal. It is divided into several sections including:

- A guided tour of individual prints in a virtual study collection that contains processes ranging from the woodcut to the modern digital print;
- A tool to compare processes using views made with the various lighting techniques and magnifications; and
- A section detailing the distinguishing characteristics of each process with step-by-step instructions on how to identify print processes.

Graphics Atlas also contains additional web pages devoted to the history of printing technologies. Figure 17 below shows the front page of the site.

The images created during the project have also been used by a number of educators (both IPI staff and from other organizations) in workshops aimed at various groups interested in developing

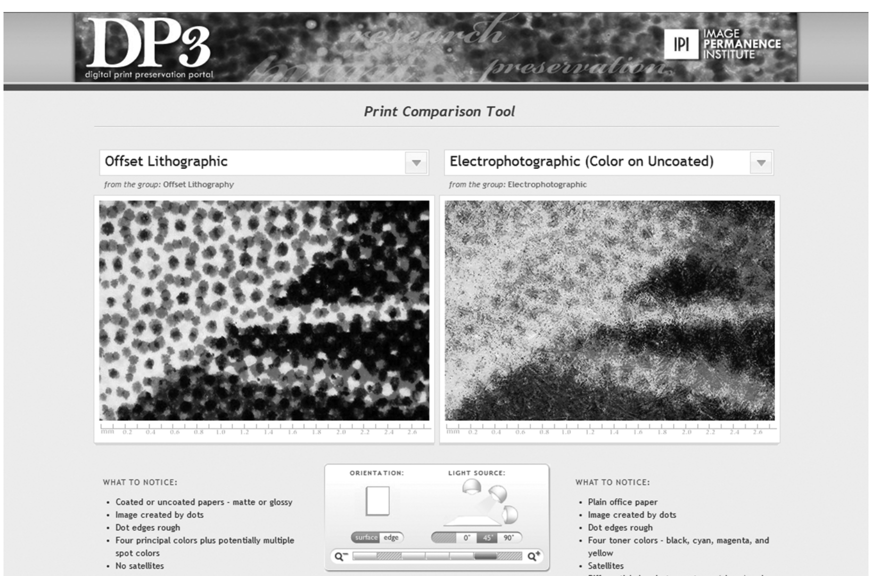


Figure 16. DP3 Project online digital print identification tool.

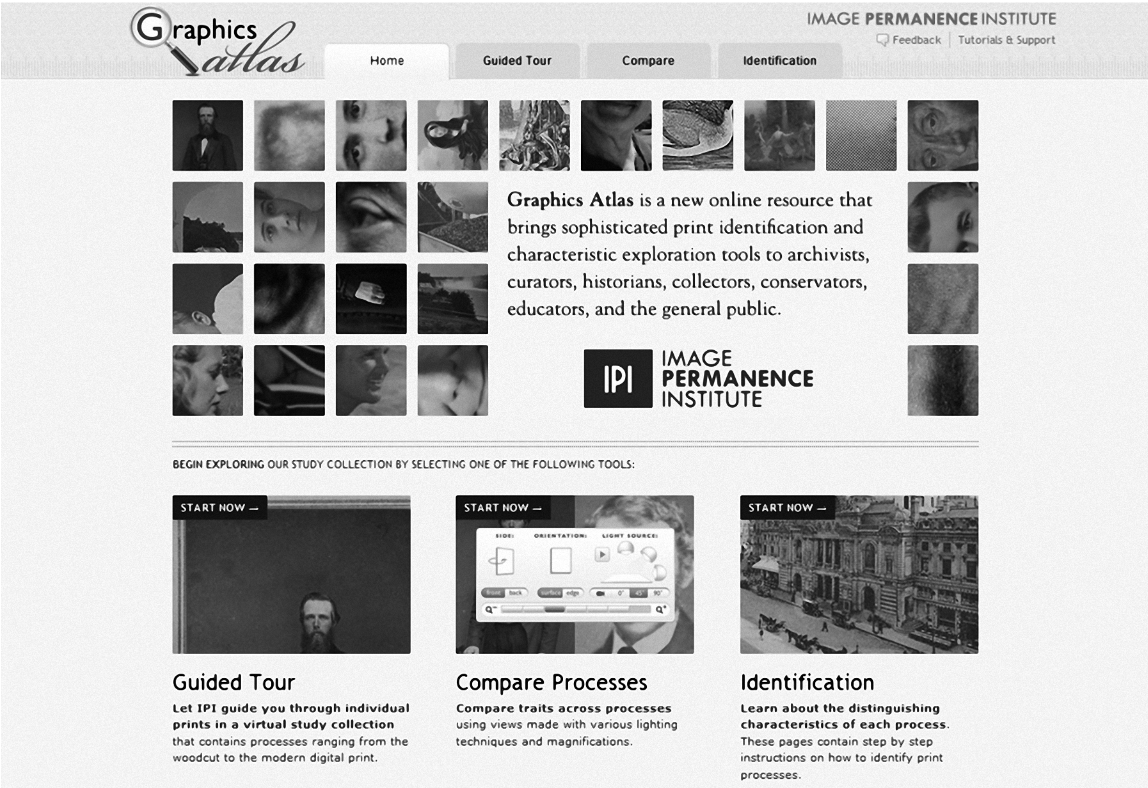


Figure 17. Graphics Atlas front page.

a better understanding of these materials and how best to identify them, including photo conservators, picture framers, archivists, and librarians.

Conclusions

The use of various imaging strategies including different lighting techniques (angles and sources) and magnification levels, as well as quantitative measurements, has been shown to aid in the characterization and identification of modern digital prints. This work has led to the development of useful online tools that are free to the public. IPI will be continuing the work into digital print characterization and identification with current goals including:

- Further improvements to the imaging techniques;
- Expanding the list of quantitative measures;
- Cataloging and defining qualitative measures;
- Developing a better set of terminology for the materials and processes; and
- Finalizing the digital print taxonomy.

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