Color Approval in the Graphic Arts

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Abstract

The demands of the graphic arts color refinement process are unique in the color imaging industry. Economic, creative, physiological, technical and behavioral factors combine to produce a lengthy and exacting color approval process. In addition to the common optimum color reproduction sub-objectives of compromise color reproduction, corrective color reproduction and preferred color reproduction, a creative color reproduction objective may be added during the iterative color approval process. In general, color appearance models and color management systems are incapable of more than a first approximation as far as graphic arts color quality requirements are concerned. Calibrated color monitors are an almost indispensable part of the color refinement process, but for approval purposes, a hard copy proof is required to fully capture the colorimetric, image structure, and surface characteristic aspects of the final printed result.

Introduction

The photomechanical reproduction process, which uses photochemical or electro-mechanical methods of color separation and a physical transfer of inked images from an image carrier to a substrate via a printing press, holds a distinctive position in the color imaging field. This distinction derives from the facts that photomechanical reproduction is the oldest commercial color imaging process, and that it is the largest volume producer of color reproductions having a physical or "hard" structure.

French scientist Louis Ducos du Hauron is credited with an early* application of three-color printing via the collotype process in 1878. His subsequent collaboration with Toulouse printer Andre Quinsac during 1883 produced some of† the first commercial photomechanical color reproductions.[1]

American inventor Frederic E. Ives was experimenting with three-color photoengraving techniques about the same time as du Hauron was developing his process. It was not, however, until 1893 that William Kurtz of New York produced commercial photoengravings for printing[2] by the letterpress process. The letterpress process was far more predictable and economical than the collotype process; consequently, it quickly became the dominant method of producing photomechanical color reproductions.

A key requirement of the early photoengravings was that they required an iterative etching process to adjust the halftone dot sizes. The metal plates were etched, proofed, and re-etched and re-proofed until the desired result was achieved. Several generations of art directors, designers and print buyers were conditioned to expect an iterative approval process. This approach persists to this day. Modern digital, image processing systems, which are used in conjunction with the lithographic and gravure printing processes and direct digital proofing systems, are still used in an iterative "get-the-color-right" approach. The approval process is far faster today, but is otherwise remarkably similar to practices of 100 years ago.

This is, however, a far more important reason than habit to explain the iterative photomechanical proof approval process. The person approving the proof is not simply spending a modest sum to purchase a set of color separations and proofs. The proof is the prototype of the printed image and, as such, is a predictor of the many millions of copies that subsequently may be produced. Once the plates are mounted on the printing press, it is virtually impossible to make refinements to the image; hence, there is a powerful incentive to take whatever steps are necessary to ensure that the color separation film and plate images are as close to perfection as allowed by the constraints of the process.

Some idea of the cost and volume considerations that shape the photomechanical color reproduction color approval process may be gained from a cursory examination[3] of the magazine printing industry. A 4-color double page in Time magazine, for example, costs an advertiser about $210,000 for a single week's issue. A copy of National Geographic magazine contains about 150 separate color reproductions (editorial and advertising) and, given that the monthly circulation is about 9.2 million, approximately 1.38 billion color reproductions are produced each year by this one publication.

Process Constraints

The photomechanical color reproduction process may use any of a wide range of inks, substrates and processes to generate an image. It is this wide choice, plus the opportunity to make extensive modifications to the image at several stages of the process, that has helped make the extended color fidelity refinement process the rule rather than the exception. The objective is to get the best out of a particular combination of materials and processes, the use of which is dictated by creative and economic factors within the perceptual limitations[4] of the human visual system.

Color Gamut Constraints[5]

Subtractive primaries should, theoretically, fully trans-

* original text read "the first"

† original text read "led to"

mit two thirds of the visible spectrum and fully absorb one third of the visible spectrum. In practice, yellow pigments approach this ideal, but magenta and cyan pigments fall well short. Magentas absorb too much blue light and cyans absorb too much blue and green light. Economic factors also influence pigment selection: many printers use cheaper magentas (e.g., Lithol Rubine) with quite poor blue light transmission in place of the more expensive but spectrally purer (e.g., Rhodamine Y shade) pigments with better blue light transmission.

Subtractive primaries should also be perfectly transparent. In practice, they are all partially opaque; yellow being the worst. Printing color sequence will, therefore, influence the appearance of the printed image.

Certain characteristics of the substrate will also influence the colorimetric properties of the printed ink film. Substrate whiteness (or lack thereof) will influence the color of thin near-transparent ink films. Poor substrate brightness will limit the density range of the reproduction and produce distorted tone reproduction. The gloss and absorptivity of the substrate will combine to further distort the printed ink film. The least distortion occurs when the substrate has a gloss value near 100 percent and an absorptivity near zero. Fluorescence (caused by the use of optical brightening agents during the papermaking process) can also exert a noticeable effect in some light tonal areas.

The color gamut of the ink-substrate system is further constrained by additivity and proportionality failure effects. Additivity failure occurs when the densities of a two color overprint (e.g., green) fail to equal the sum of the densities of the two colors (e.g., cyan and yellow) used to produce the overprint. There are a number of factors that contribute to additivity failure, but poor ink transfer (trap) over a previously-printed still-wet ink film is a major contributor to this effect in lithography (the ink is dried between colors for gravure printing, but is not for lithographic printing).

Proportionality failure occurs when lighter tints of a given color fail to retain the same proportional colorimetric properties as solids of that color. The problem is particularly noticeable in halftone processes (lithography more so than gravure), especially when coarse screens and coated paper are used. In general halftone tints become grayer and less pure than a solid of the same color.

To summarize, additivity failure restricts the saturation of the red, green and blue overprint colors, and proportionality failure reduces the gamut of light halftone values for all hues. These restrictions are on top of the gamut limitations imposed by the initial ink and substrate selection.

Image Structure Constraints[6]

Image structure, to a large degree, is dependent upon the resolution of the imaging process. In the case of lithography, which is generally recognized as having the highest resolution of the printing processes, the smallest recordable spot is about 8 microns.

Halftone images have been recorded with a digital structure since the early 1970s. The discrete nature of these images produces trade-offs between screen ruling fineness and tonal steps. In practice the combination of a 250 lines per inch halftone structure combined with 145 tonal steps, is a generally satisfactory compromise.[7] Under such conditions, the image recording resolution of the halftone dot structure is about 3,000 lines per inch. Digital images do, of course, contain less information than analog images but most of the time the differences are beyond the thresholds of the human visual system.

Resolution is constrained by the nature of the substrate and the printing process; newspaper printing, for example, is usually restricted to about 85-100 line per inch screens whereas fine art or photography books may be printed with screen rulings as fine as 250-300 lines per inch.

Image sharpness is constrained by the maximum density of the process. Maximum density may range from a low of 1.10 for newspaper work to about 2.50 for the best substrates and high gloss inks. Color scanners are equipped with edge enhancement controls that may be used to increase apparent sharpness. The excessive adjustment of such controls can, however, emphasize graininess and cause the image to appear unnatural.

Sharpness is also influenced by how well the separated images are printed in register with each other. As a general rule of thumb, register may vary by up to one-half a row of dots and remain unnoticed to most observers. Higher speed presses and lighter weight substrates increase the chances of misregister.

Interference moiré patterns occur when halftone images are overprinted at different screen angles. In practice, especially at very fine screen rulings, these patterns tend to be unnoticed or unobjectionable. Multi-angle halftone strategies will, however, reduce resolution. Same-angle halftones are generally ruled out of consideration because of potential color control problems.

Image structure optimization is often reduced to tradeoffs between one image quality factor and another. The importance of one factor over another is often determined by the content of the image and the intended purpose of the image.

Process Quality Enhancement

Quite apart from choosing the best substrates and inks for color reproduction, printers have, for many years, used a variety of techniques to improve the quality limits of the products they produce. The use of extra colors and overprint varnishes are well known strategies to expand color gamut and tonal rendition. Until recently, however, the extra-color strategy was constrained by halftone moiré concerns.

The pale blue and pink supplementary colors that were chosen by printers to overcome the proportionality failure effects of cyan and magenta inks could be printed without moiré concerns because of their low contrast and the fact that cyan and magenta dot values tended to be low in those areas where pale blue and pink dot values were high.

The red, green and blue supplementary colors that were chosen by printers to overcome additivity failure problems were generally restricted to solid or 100 percent values because their contrast was such that moiré problems would occur if these colors were printed with a full range halftone tonal structure.

The introduction of stochastic or random structure screens has eliminated moiré problems and allowed the printer to choose any supplementary colors that are best suited to enhancing the image at hand. Stochastic screens also improve image resolution of the reproduction.

Some early versions of stochastic screens introduced a grainy pattern into smooth tonal areas, but this problem has been greatly reduced in recent years. The small element size associated with stochastic images does cause some color proofing problems, and the stochastic screen press dot gain is higher than that of conventional screens. Compensation for the latter condition may, of course, be built into the color separation images.

Process enhancements are usually restricted to the lithographic process because it is here where the gamut-restricting effects of additivity and proportionality failure are most common. The gravure process, by contrast, has little additivity failure because the inks are dried prior to the transfer of subsequent inks, and it also has little proportionality failure because the variable depth-variable area structure of gravure cylinder images tend to produce printed ink films in lighter tonal values that are closer to continuous films of color rather than halftone dots.

All printing processes use a black printer to help improve tone reproduction, and all may make use of overprint varnishes to similarly improve contrast and saturation. Such enhancements are not always desirable; a watercolor or pastel illustration or painting should usually be produced on a low gloss substrate.

Color Reproduction Objectives

The choice of a color reproduction strategy to suit the particular requirements of the image and the purpose for which it is to be used is not a simple matter in light of the vast array of production materials and processes which may be used. In fact, the complexity surrounding the choice of color strategy probably explains why color adjustment techniques continue to be applied in an iterative (and often localized) manner. There are three general color reproduction objectives that tend to be pursued in the printing industry: exact color reproduction, creative color reproduction and optimum color reproduction.

Exact Color Reproduction[8]

The conditions required for exact printed color reproduction rarely occur in practice. The conditions include: reflection original, no non-gamut colors, a D_{max} equal to or less than that of the printing process, same-size reproduction, viewed by identical light sources, identical surface characteristics, and no fluorescence problems.

An exact color reproduction objective usually arises when reproducing merchandise samples in catalogs, or reproducing fine or commercial art in the form of a poster or facsimile reproduction. The occasions when exact color reproduction is desirable and achievable are rare, therefore, optimum color reproduction objectives tend to be applied to originals when the intent but not the means for exact reproduction is the reality.

Creative Color Reproduction

The term creative color reproduction may sound like an oxymoron and, to some extent, it is. The process of creative color reproduction usually starts out as a simple exact or optimum color reproduction objective. As the photo-mechanical process unfolds, however, the juxtaposition of images and graphic elements suggests certain enhancements to the designer or art director that were impossible to previsualize. The influence of the particular substrate and inks chosen for the job may also prompt further image color modifications in order to more fully exploit the serendipitous amalgam of images and materials.

The urge to constantly manipulate tonal and color values in order to achieve creative excellence is part of the artist's temperament. Ansel Adams, the great landscape photographer, used a variety of enhancement techniques[9] when producing prints from his negatives. In fact, he used different techniques as his creative vision changed; this resulted in different interpretations of the same negative.

Graphic designers are well grounded in artistic principles and are alert to opportunities for extracting the creative potential from a given set of conditions. The fact that the subsequent color separations may be used to generate millions of printed images simply reinforces the desire to "fine tune" the separations.

Optimum Color Reproduction[10]

Optimum color reproduction is the objective for the vast number of printed color reproductions. This objective has three sub-objectives which are not usually treated as discrete activities but rather are pursued simultaneously. The sub-objectives are: compromise color reproduction, corrective color reproduction and preferred color reproduction.

Compromise color reproduction is the term used to describe the compromise which must be made to produce the best reproduction under non-ideal circumstances. The circumstances that lead to this approach are: original and reproduction are different sizes; original has a greater D_{max} than the reproduction; there are non-gamut colors in the original; the original is a transparency; the surface characteristics of the original and reproduction differ; and the image structure qualities of the reproduction do not match those of the original.

The nature of the chosen compromises will vary accord-ing to the requirements of the end result and the content of the original image. Tone compression, for example, will be non-linear and tend to favor the "interest area" of the image. Saturation compression will often be applied equally to all colors of a particular hue; but in some cases, non-gamut colors may be ignored in favor of a more faithful reproduction of gamut-boundary colors. The subsequent results may suggest the need for deliberate hue shifts.

Scale differences between original and reproduction necessitate tone reproduction adjustments. Great reductions require reduced midtone density, whereas great enlargements of the same image require increased midtone density, both as compared to same size reproduction.

Image structure dynamics are also driven by the needs of the job relative to the content of the image. Graininess and edge enhancement, resolution and sharpness, resolution and graininess, moiré and color variation, are some of the sub-optimization relationships that are considered. The elements of image structure also interact with the colorimetric properties of the reproduction to prompt further modifications or adjustments.

Corrective color reproduction is that aspect of optimum color reproduction concerned with correcting distortions of the original. An original color transparency may, for example, have an objectionable color cast that must be removed in the reproduction. More common, however, are those cases when a color original contains "normal" distortion which must be corrected. A color transparency for a fashion catalog may not accurately reproduce a particular fabric color. An actual sample of the fabric in question may be submitted to guide the color adjustment process.

Some color distortions in the original may, of course, be preferred and should not be removed. A photographer may choose a particular type of transparency material because it reproduces certain subjects to advantage. Such subjects as landscapes, portraits or metallic industrial products could benefit from the judicious selection of one brand or type of film over another.

Preferred color reproduction[11] is that aspect of optimum color reproduction concerned with deliberately distorting colors to make the resulting reproduction more pleasing to the final observer. Common distortions include: reproducing Caucasian skin color slightly tanner than normal, reproducing green grass and foliage at higher saturation than normal, and reproducing sky at a bluer than normal hue. Postcards and calendars, in particular, routinely incorporate preferred rather than natural colors. Many brochures, especially for the travel and real estate industries, also make extensive use of preferred color reproduction strategies.

Some originals already incorporate the preferred distortion from reality and may be treated as a compromise color reproduction type of original. In yet other cases, the desired distortion may be considered part of the creative color reproduction objectives.

It is useful to explore all objectives of the photo-mechanical color reproduction process in order to avoid thinking of it in simplistic terms that tend to exclude the "messy" but critical color adjustment and refinement tech-niques that represent traditional yet essential elements of the process that produces excellence. In practice, however, color quality objectives are addressed simultaneously and involve a good deal of human judgment that is difficult, or impossible, to quantify.

Color Approval Dynamics

The color approval process that is followed when evaluating a photomechanical proof can be likened to the trial and evaluation stages followed by the fine art photographer who is trying to produce the perfect print. The photographer is producing a single work of art that expresses a particular vision, whereas the art director is approving the production of images (the color separations, as represented by the proof) that will be used to generate many copies of a particular vision. In each case a single individual makes the judgment; there are, however, some significant differences in the circumstances of the judging process.

Photomechanical proofs are usually evaluated under the pressures of time. This situation is quite common in the advertising reproduction segment of the industry and less so for the packaging sector. Time limitations restrict the number of quality iteration cycles that may be used and increases the pressure to produce a first proof that is very close to the vision of the art director.

The economics of printed products vary considerably: the consumer may pay as little as 50 cents for a newspaper and as much as $100 for a fine art photography book. The quality approval process (by both the art director and the ultimate consumer) is likely to be much more cursory for the newspaper than it is for the book. The quality of the advertising pages in the newspaper will, however, be subject to considerable scrutiny by the purchaser of the advertising space.

A specific color temperature (5,000 K) light source is part of a comprehensive viewing standard for the evaluation of printed matter. In practice, however, printed images will ultimately be viewed under a vast array of lighting conditions that includes supermarket fluorescent lights, home tungsten illumination and the great variety of daylight conditions. There is the very real possibility that metameric matches made under the standard conditions will prove to be unsatisfactory under supermarket or home lighting conditions. There are instances where large companies have developed their own internal lighting specifications for evaluating color proofs, but the simplicity of relying upon a standard source usually outweighs the metameric match concern. "Standard" viewing conditions do vary from site to site for reasons that are due to both variations within light source manufacturing and to local distortions of such specifications as transparency surround dimensions.

The color vision of the persons making color proof evaluations will vary from individual to individual. Leaving aside abnormal color vision considerations, color vision will change with age[12] and may lead to significant color perception and communication problems. The person approving the proofs of brochures for a multimillion dollar advertising campaign is quite possibly a senior executive whose color vision may differ significantly from that represented by the CIE standard observer.

There are psychological and situational factors that will also influence the color proof approval process.[13] The print buyer is often cast in the role of print critic whose duty it is to find fault with the proof. The reasonableness of such criticisms is often dependent upon organizational, interpersonal and situational factors that have little to do with the actual appearance of the proof. The outcome becomes, in part, the product of a sometimes-adversarial buyer-seller negotiation process rather than a pure expression of color excellence.

To summarize: the fine art photographer and the art director (or print buyer) have a common goal; i.e., to achieve the perfect image (within the constraints of the materials) that best represents their vision of aesthetic and technical excellence. The outcome, in each case is influenced by the viewing conditions and the color vision of the person making the evaluation. The photomechanical proof approval process is further influenced by the pressures of time, economic factors and the dynamics of the purchasing process.

There are printed products that require "pleasing" color quality of the type represented by machine-generated color prints for the consumer segment of the amateur photography market. It would be incorrect, however, to assume that many printed products belong to this category. In fact, most types of printed product proofs are more properly compared with the custom printers produced by fine art and professional photographers.

Color Quality Optimization Technology

Highly skilled craftsmen routinely produced excellent color reproductions in the early days of the process color printing industry. The time required to produce such quality was extremely long (days or even weeks) by today's standards; therefore, the use of the photomechanical color reproduction process was restricted.

The first commercial use of color separation scanners during the early 1950s and the expanded availability of 4-color presses (especially for the lithographic process), led to the rapid expansion of the photomechanical color reproduction process. The commercial pressures of high quality and quick production within an expanding market created the need for improved approaches to the quality optimization process.

The widespread availability of inexpensive, powerful computer systems has prompted the development of mathematical models that are designed to quantify the relationships between originals and reproductions.

The Neugebauer equations of 1937 represented an early attempt to quantify the original vs. reproduction relationships. In practice, however, the reproduction applications of these equations have proved to be quite limited.

The variations between viewing conditions, original and reproduction media, and such other factors as reproduction scale have been expressed in the form of color appearance models. A number of such models[14] have been developed in recent years. The influence of such factors as the scanner's color response and the properties of the image recording media on the appearance of the reproduction are encoded within the color management systems[15] that are incorporated within image processing systems for the printing industry.

All color appearance models and color management systems are based upon certain assumptions and restrictions that limit their performance. The predictions of the models often produce satisfactory results for the consumer photo-graphic market and also for certain kinds of on-demand or editorial printing. The high quality printing market is, however, well beyond the capability of the purely mathematical approach. Models cannot select user-defined "interest areas" or critical colors and are quite incapable of coping with the creative adjustments that are often part of the photo-mechanical reproduction process. Significant differences between the color vision of the art director or print buyer and that represented by the CIE standard observer will also invalidate the predictions of models for the highest quality work. The models are useful, however, for producing a first approximation that can serve as the foundation for further refinement.

The first use of color monitors for evaluating color separations prior to printing occurred during the early 1970s; today their use is practically universal. A properly calibrated (restricted gamut) monitor is an invaluable aid when making tone reproduction manipulations, non-gamut color compres-sion, compensatory hue shifts, color distortion adjustments, and creative enhancements. The color monitor is an unsurpassed technology for rapidly assessing the product of the iterative adjustment process.[16]

Color monitors do have some drawbacks: they are ill-suited for assessing the influence of substrate surface characteristics on the reproduction, and they do not adequately represent the sharpness, resolution, moirÈ, graininess, and other aspects of image structure. Monitors must be carefully calibrated and used under well-defined viewing conditions if they are going to be accurate predictors of the subsequent printed colors. The predictions of the monitors may also fail if the monitor is not large enough to display the image at the final printed size, or if the monitor is not capable of displaying the entire gamut of the reproduction process.

The hard copy proof, which can either be in the form of a direct digital proof or an indirect digital proof, is the best way of representing the color, image structure, and surface characteristics of the reproduction. Theoretically, a press proof is the best proof when the highest quality is required. Press proofs most accurately predict final appearance as long as the proof was made under conditions identical or similar to the job's printing specifications. The non-press proofs (direct or indirect) can sometimes fail to adequately represent such factors as ink trap, surface gloss or texture, image structure, and the colorimetric or transparency properties of the ink pigments.

Off-press proofs are more desirable than press proofs from the cost and speed points of view, but to be a valid predictor the appearance qualities must be similar to those of the printing materials. Direct proofs made from digital data are most likely to achieve acceptable fidelity because of the great flexibility afforded by such systems.

In many cases (e.g., web offset lithography) it is impractical to produce press proofs of an image prior to commencing the production run. An off-press proof will generally provide a close approximation of the printed image, but the actual differences, which will be discovered during the press makeready process, may prompt the print buyer to request on-press color adjustments.

On-press color adjustments are very limited: different color sequences will influence appearance as also will increases or decreases in ink film thickness of one or more of the inks. Press-related adjustments are global in nature and are in no way a substitute for a poor set of color separations. Deviations from plant standard makeready procedures are, furthermore, likely induce production run variability. The printed image is, of course, the final product of the photomechanical reproduction process and the temptation to introduce perceived improvements during the makeready process is often difficult to resist for those making the color approval.

Conclusion

Color proofs are subject to intense scrutiny because they establish the basis for thousands or even millions of subsequent prints. A number of color reproduction objectives are brought to bear during the proof approval process, namely: corrective adjustments, tone and saturation compressions, preferred distortions and creative enhancements. A single person generally approves the proof. This individual's judgment will be influenced by these factors: creative intent, interpretation of customer or final consumer's evaluation of the image, color vision, and role in the proof buying process. In other words, color proof excellence is a somewhat idiosyncratic process that is driven by the economic and production realities of the job, the physiological and psychological characteristics of the print buyer, the picture content and end use requirement of the image, and the print buyer's individual perception of creative and technical excellence.

Color appearance models and color management systems are useful in establishing a good initial reproduction of an original but, for high quality work, their use is necessarily limited. Color monitors, with their direct feedback have made it possible to preview color adjustments prior to making the separations. Valid color evaluations are dependent upon accurate monitor calibration and viewing conditions. The image structure and surface characteristics of an image can only be evaluated via a tangible proof. Proofs made directly from digital data have the potential to produce accurate matches to any one of several printing conditions. A model-monitor-proof process of photomechanical color reproduction is the suggested foundation for producing high quality results with quick approvals.

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