# Requirements for Virtual Proofing

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**Abstract:** Investigations spanning several years in the area of soft-proofing on display have identified the following potential barriers to achieving contract proof-quality on display:

1) Correlation of CIEXYZ and CIELAB between hard copy measurements and display measurements
2) Effects of flare
3) Effects of resolution
4) Absolute accuracy of measurement devices
5) Absolute accuracy of calibration technology
6) Impact of variations between manufacturers and between lots of the fluorescent tubes used for illuminating hard copy
6) Effects of non-opaque paper
7) Lack of robust system level control of profiles, calibration state, etc.

Once these topics are addressed to an adequate level of precision, consistent matches can be achieved between contract proofs or press proofs and the corresponding image viewed on display for a wide variety of reproduction conditions ranging from high quality commercial printing to newsprint. Virtual Proofing is the term used to indicate contract proof-quality color accuracy on display achieved automatically on multiple displays even when they are compared side by side to each other as well as compared to a contract proof or press proof illuminated in a viewer. This paper will seek to describe the solutions necessary to overcome each of the barriers listed above, and to confirm that virtual proofing now has a strong technical foundation.

## Introduction

This paper will attempt to describe at a system level what is required in order to achieve virtual proofing, i.e. the simulation of CMYK contract proofs and press proofs on RGB displays with predictable, accurate color both locally and remotely.

## Virtual Proofing vs. Soft-Proofing

One may well ask, "Why the term virtual proofing rather than soft proofing?" The answer is that the latter term can mean different things to different people, from rough draft quality to contract proof quality in terms of color. Likewise, the degree of certitude and control regarding color may vary in expectation from “little confidence” that the correct profiles and setup were used to view color to “100% confidence” that the desired color appearance was viewed by the recipient of the image.

Contract proofs are typically a very good (not perfect) match to the targeted printing press standard. The key attribute of contract proofs which enables them to be used for color communication between different locations and individuals is consistency. As long as all the parties involved (both sender and recipient) know the relationship between the specific color properties of the contract proof and their press, and as long as they can depend on that relationship to remain the same, all will be well.

Furthermore, since contract proofs can be physically sent to a remote location, marked up, and returned to sender, there is no ambiguity regarding what the recipient sees, what modifications are requested, and (in the case of color sign-off) what the color expectation is of the client when the job is finally printed.

Soft proofing is already used heavily today for non-color critical viewing. The most common form of soft proofing is to e-mail a PDF format file. When viewed with standard software products such as Adobe® Acrobat®, a reasonable soft proof is obtained with regards to position, geometry, layout, fonts, etc. The logical next step is to offer the same rapid response time for a virtual proof with the simplicity of opening a PDF file, combined with a guarantee of accurate color match to the physical reality, i.e. to the CMYK hard copy normally used for high quality contract proofing or the press proof itself.

In light of the above discussion, what are the attributes of virtual proofing?
The attributes we would propose are:

- Excellent visual match between RGB display and contract or press proof
- Quality must be adequate to replace functionality of contract proof
- Primary limitation is resolution and uniformity of display, not color or consistency
- Automatic calibration and certification of system setup
- Certitude of accurate remote viewing similar to sending a CMYK proof by mail
- Ability to track annotations and to confirm annotations were made on certified system
- Ability to swap components without subjective adjustments to maintain color accuracy

In order to achieve the above, the components for virtual proofing can be summarized as follows:

- Acceptable display technology
- Accurate calibration technology
- Accurate, high quality ICC profiles
- Corrections to CIELAB for accurate viewing of CMYK->RGB on display
- Optimal scaling and sharpening
- Accurate measurement device
- Stable, uniform, and accurate D50 illumination for hard copy
- Color management system architecture that enables Administrative control of profiles
- RIP support for interpreting vector files
- Support for multiple workstations on WAN and LAN
- Password protection for annotations
- Logging of calibration state when performing annotations
- Control of factors affecting color including warm-up times, OS settings, etc.
- Eyedropper capability for confirm CMYK values as well as expected CIELAB measurement for all printed colors

From the pure color accuracy and robustness point of view, we would suggest that all customers planning to enter true virtual proofing confirm the following either yourself or in conjunction with your vender:

- Select challenging test images (e.g. large CMY and K gray areas, SCID Images, etc.)
- Compare two adjacent displays next to hard copy viewer
- Compare virtual proof and hard copy in all aspects
- Color match accuracy
- Acceptable uniformity
- Neutrality of grays
- Day to day consistency
- Confirm all components can be swapped without loss of quality (measurement device, display, hard copy viewer, etc.)

**Are the Display Technologies Ready for Virtual Proofing?**

Our experience with customers thus far indicates that LCD technology in particular is ready for virtual proofing with regards to day to day stability, improved angle of viewing consistency, etc.

The most significant potential hardware issue that users must determine for themselves is the issue of uniformity. The quality of uniformity across a display (top to bottom, left to right) can vary depending on price and size of display. Also note that if one is comparing two displays which lack uniformity side to side, the accuracy in the center may be very good, but the adjacent outer edges of the two displays may exhibit differences.

This may well raise the issue of whether displays with less than perfect uniformity can be used for contract proofing. Speaking from our own experience with Kodak Polychrome Graphics (KPG) customers, thus far the answer has been overwhelmingly "Yes!"

The reason for this is simply this: as long as the overall appearance of the proof on the display is very close to the overall appearance of the contract proof or press proof, the virtual proof can be used as a contract proof. If an ultra-precise 1% color judgement is required in a specific area such as a face, the user has the option of momentarily positioning that area in the center of the screen for color confirmation.

This highlights one very fundamental difference between hard copy proofing and virtual proofing: the user must live with the uniformity errors of a hard copy proofing system, but is able to compensate for slight lack of uniformity in a display by using the approach described above.

This is why most contract proofing systems have extraordinarily tight specifications on the uniformity of their papers, colorants, methods of imaging and exposing, etc. If uniformity errors in the individual colorants exceed about 1% or 1 DE, noticeable additive error can occur for the CMYK colorants as they mix together.

By comparison, our experience thus far with virtual proofing customers indicates that as long as the quality of the overall display is reasonable (i.e. a few percent or a few delta E) but the tolerances after calibration in the center are VERY accurate and consistent (i.e. less than 1 $\Delta E$ error), virtual proofing can be very successful. In our own system as an example (KPG Matchprint Virtual Proofing System) we spend a lot of time determining via measurement and visual assessment which displays are affordable **and** have reasonable (not perfect) overall quality in terms of uniformity.

### Component and System Requirements for Virtual Proofing

Virtual proofing can be broken down into the following key components: display hardware, calibration technology, device profiling and conversion, correction technology for CIELAB, color management control, and system level infrastructure for file display, transfer, and annotations.

**Display Hardware Technologies**

Current RGB display technologies generally fall under two categories: CRT and LCD. Although in the U.S. LCD is rapidly taking over, in many parts of the world CRTs are still heavily in use. The pros and cons of these two technologies are as follows:

- CRT Pros – Mature technology, good uniformity top/down/left/right, smooth analog voltage-based tone behavior, little change in color appearance when images are viewed from an angle.
- CRT Cons – Lack of intensity (100 candellas/$m^2$), resolution limited to 100 dpi, heavy bulky equipment.
- LCD Pros – Capable of bright intensity (up to 3 times the intensity of CRTs), higher contrast ratios than CRT (1000:1 vs. 200:1), up to 200 dpi resolution, much more compact and portable than CRTs
- LCD Cons – Slightly lower quality uniformity top/down/left/right, digitally driven tone reproduction may be less smooth, some shift in color appearance when images are viewed from an angle.

At this point in time, our customers have made it very clear to KPG that the pros of LCD far outweigh the cons: for that reason current versions of Matchprint Virtual Proofing System only support LCD. It should be noted that LCD is a growing technology: each year the LCD venders are improving the quality of their displays and lowering the costs.

**Requirements for Display Calibration**

There are many good display calibration technologies on the market today. Private and public testing has indicated that displays can typically be calibrated to a tolerance of 2 – 4 $\Delta E$.

Although this error is considered small by many standards of comparison, customer testing at KPG has indicated that when the total difference between two displays is larger than 1 $\Delta E$ on average (most notably for gray balance) the visual difference is quite noticeable. Hence, even very good calibration software may not be adequate to achieve virtual proofing.

One reason why a very tight specification is needed for virtual proofing calibration is due to an important property of hard copy proofs: generally speaking, the consistency of paper is quite good. A user can choose to use paper from one lot for proofing, or can specify a tight tolerance from its vender for the paper it uses for proofing.

For example, analog and digital proofing products such as KPG Matchprint Analog Proofing System and Matchprint Digital Proofing Media have always offered the option of purchasing paper that is tightly controlled with regards to color. Typically these color specifications have been very tight: a customer would be very displeased if more than 1 ΔE variability were to occur in gray balance of the paper.

This highlights that "not all ΔE's are created equal". A tolerance of 2 – 4 ΔE may be very acceptable for the chroma of saturated yellows. However, a tolerance of 2 – 4 ΔE may be very unacceptable for whites and grays.

For this reason, our recommended circle of tolerance for calibration of whites, grays, and near black is approximately 0.5 ΔE average error for the calibration itself, with an assumed tolerance of 0.5 ΔE measurement device to measurement device. (Note that these tolerances refer to center of display only.)

However, it must be noted that it is not enough simply to specify a tight tolerance as a requirement for calibration. There is a second requirement that is equally important, which is calibration integrity, also known as smoothness.

Whereas the eye can perhaps tolerate errors of 0.5 – 1.0 ΔE in terms of absolute accuracy, it cannot tolerate these errors for colors which are adjacent to one another in color space. This means that if the human eye views a gray blend ranging from white to black, the smoothness required (i.e. the absence of DE noise and variability up the tone scale) in order to avoid artifacts, banding, etc. nearly exceeds our current ability to measure. Thus, the best way to avoid the possibility of these types of issues is as follows:

- Along with quality of uniformity (top to bottom, left to right) certify in advance that the uncorrected tone behavior for a certified display is artifact-free.
- When performing corrections and calibrations, ensure that number of "control points" for characterizing and for correcting are as few as possible.

For example, if calibration software measures 20 levels of gray ranging from white to black, it is unwise to characterize and correct based on 20 individual control points. Smooth characterization and corrections curves comprising of 2 – 5 control points should be used to ensure artifact-free virtual proofing.

The display system for virtual proofing (CRT or LCD hardware + calibration software/hardware) *must* employ accurate calibration technology combined with smooth tone correction. As one example of fulfilling the requirements above, the mathematical details for Matchprint Virtual Proofing System calibration are described in a published patent (Edge, 2004a).

Typically, calibration entails a two step process: optimizing the white balance and then optimizing the gray balance. As a general rule, it is desirable to perform these optimizations within the display itself if the support exists to do so. If not, the optimizations can generally be performed via the video card look up tables.

Adjusting the white point generally entails optimizing the value of R,G,B gain (in the case of an analog system such as a CRT), or optimizing the look up table (LUT) values $R_{max}$, $G_{max}$, $B_{max}$ in the case of a purely digital system controlled by R,G,B LUTs. The optimization performed minimizes the error between measuring the RGB white (RGB=255) displayed on screen and the targeted value of $XYZ'_{D50}$ where the necessary CIE corrections described below have been applied.

Next the gray balance must be optimized. This can be performed by the following process:

- Characterize the current tone response for RGB as indicated by gray scale data
- Create an inverse LUT for each RGB channel and apply to the existing LUTs residing in the video card or in the display itself
- Recheck the gray balance to confirm close match to target

The exact target selected is at the discretion of the vender for virtual proofing. However, whatever target is selected for calibration, the characteristics of the target must be reflected in the ICC profile created for the display. As an example, all Matchprint Virtual systems are calibrated to a theoretical perfect RGB space with a gamma of 2.2. This means that a* and b* are as close to zero as physically possible for R=G=B using the value of $XYZ'_{D50}$ as the white reference value for CIELAB calculations.

An advantage of virtual proofing over hard copy proofing is that it is relatively easy to enforce calibration on a daily basis. Since there are times when calibration is not required, users can view and annotate images on a system that has not been recently calibrated. However, the annotation software must communicate with the calibration software to confirm whether the system is in a color accurate state, and register the Yes/No status in the annotation window itself. This Yes/No status is maintained permanently in the annotation to ensure that if there is ever a question, participants can later confirm whether a comment was made in a color accurate state.

One may ask whether 24 hours is too frequent for calibration considering the stability of LCDs. To those who may believe that 24 hours is too frequent, one should point out that calibration confirms not only stability of display state, but also ensures that all aspects of the system that affect color are set correctly, including display profile, LUTs, display controls, etc.

**Profile Quality Requirements for Virtual Proofing**

The profiles for characterizing the CMYK print being proofed and the RGB profiles for the display must likewise be very accurate with a high degree of integrity and smoothness. The profile information defining balanced CMY grays and K-only grays must be similar to the calibration tolerances described above and likewise must be defined in the smoothest way possible to ensure artifact-free proofing.

Ideally, "intelligent" profiling should be used rather than "brute force". By "intelligent" is meant profiling where the physical behavior of the system is described in the form of a single equation, with as little empirical correction as possible. This tends to ensure an authentic as well as color accurate appearance to the virtual proof. By "brute force" is meant approaches that are entirely empirical – essentially "connecting the dots" (i.e. the measurement values) by means of splines or polynomials. A detailed example of building intelligent profiles can be found in the patent literature (Rozzi, 2001).

In general, the accuracy of the profiles should be comparable to the known accuracy of measurement. Typically, due to inevitable variability in measuring press proofs, an average error of 1 - 2 ΔE with a maximum error of 3.0 – 5.0 ΔE for non-gray colors is reasonable depending on the quality of the print being profiled (i.e. lower error for SWOP-like printing, higher for newsprint-like printing).

The best ways to ensure smoothness is

- View the 3D gamut and data plots of curves for the profile using tools like Apple ColorSync Utility; and
- Perform a visual assessment of critical images containing many blends, vignettes, smooth shade objects, etc. using these profiles.

For very thin, non-opaque papers, there is a further requirement for optimal simulation of proof or press sheet appearance on the display. Internal comparisons at KPG and at customer sites have confirmed that a neutral 50% reflective backing should be used for CIELAB measurement. Profiles need to be generated from data measured in this fashion. Comparisons of rendering CMYK to RGB on display using absolute colorimetric rendering indicate the following:

- Virtual proofs using profiles based on data measured on black backing look "dirty"
- Virtual proofs using profiles based on data measured on white backing look "washed out"
- Virtual proofs using profiles based on multiple sheets of the non-opaque paper look "washed out" although not as severely as using a white backing
- Virtual proofs using profiles based on a 50% neutral gray backing looked closest to the actual printed sample

In retrospect, these results became intuitively obvious for two reasons:

- Usually, the samples printed on non-opaque paper are viewed in a light booth on 50% neutral gray surfaces
- Light booths are always 50% neutral gray, not black, white, or off-white

Further discussion on this topic can be found in the patent literature (Edge, 2004b).

**Requirements for CIELAB Correction**

When the KPG virtual proofing project first began, there was a consistent theme that was heard from customers and color management consultants who had implemented soft proofing: when the measurement values of CIELAB and CIEXYZ were in good alignment between soft proof, hard copy proof, and viewer illumination, there was still a significant visual discrepancy that required manual correction.

Subsequent research at KPG confirmed that errors appear to exist in the currently defined XYZ observer functions. These errors, which are too small to observe when comparing similar media such as printed samples under the same illumination, become quite noticeable when comparing different media with different "illumination". Note that the equivalent of "illumination" for virtual proofing is the calibrated white point of a display, i.e. the default white appearance of RGB=255.

This assumption, it should be emphasized, is by no means universally accepted or agreed upon by either the CIE, ICC, ISO, or any other standards body. In fact, there are many who would consider such a proposal "heresy". So it should be emphasized that this is merely the assumption and observation made by the KPG labs which has resulted in fairly successful "data validation" by users of virtual proofing in the industry with demonstrated color acuity.

In defense of this assumption, I would like to point out the following quote (Fairchild, 1998) on the topic of the two degree and ten degree XYZ observer functions: "It is important to be aware that there are two sets of color matching functions established by the CIE…this was prompted by discrepancies between colorimetric and visual determination of the whiteness of paper…The two standard observers differ significantly… differences are computationally significant but certainly within the variability of color matching functions found for either 2 degree or 10 degree visual fields … (they) can be thought of as representing the color matching functions of two individuals."

The requirements for CIELAB corrections that enable virtual proofing are as follows:

- There should be a generic L*a*b* correction for all papers, printed colors viewed under D50 illumination, and their associated profiles when rendered to RGB for any one category of display. This correction will be different for two different types of display to the extent that the illumination and colorant spectra of the two displays are significantly different
- CMYK printed images with certified CMYK profiles should require no significant or systematic correction when rendered to RGB display by means of the CIELAB correction
- Accurate CIELAB correction is assumed to be achieved when "suggested corrections" or "suggested improvements" submitted by independent expert observers sum to zero.

Since human preference and subjectivity are inevitable when comparing significantly different media such hard copy proofs and virtual proofs, the best one can achieve is to eliminate all systematic perceived color matching errors amongst a population of observers.

The profile and CMM technology for converting to the local display RGB must include the corrections to XYZ mentioned above. Detailed mathematical descriptions can be found in the patent literature (Edge, 2002a). Suffice it to say that a majority of the errors in CIEXYZ and CIELAB can be addressed in the form of chromaticity corrections to the white point and RGB primaries:

$$\begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} = M_{Corr}^{-1} M_{Meas} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

where

$$M_{Meas}(R_x, R_y, G_x, G_y, B_x, B_y, W_x, W_y,)$$

$$M_{Corr}(R_x', R_y', G_x', G_y', B_x', B_y', W_x', W_y')$$

This invention has to do with correcting the XYZ data measured on displays to correlate with XYZ data measured on CMYK hard copy. When accurate CMYK profiling is combined with the RGB rendering described in this patent application and with accurate display calibration, the major technical barriers to virtual proofing are removed.

**Administrator Control within Color Management Architecture**

Finally, a virtual proofing requires system level infrastructure for color management in order to work reliably. This infrastructure must allow flexibility and control on the part of a "Color Administrator" who in turn determines how all others will view images with regards to color and proof simulation.

Color management infrastructure today as embodied in ColorSync® (at the OS level) and ICC support by applications such as Adobe PhotoShop® (at the application level) are designed to provide ultimate flexibility. Files can be converted or rendered to a display device according to the preference of the user. This type of system is very desirable in the hands of a color expert, but can be very undesirable for a workflow involving many people with varying degrees of skill level in color management technology.

The ultimate system for both local and remote virtual proofing is one that permits adequate choice and flexibility in the hands of a color expert (referred to henceforth as the "Administrator"), but which ensures complete control by the Administrator over the entire workflow. In other words, the Administrator should control how color images are displayed to all other participants in the workflow.

**Requirements for Measurement Devices for Calibration of Display**

An accurate calibrated system requires an accurate measurement device. Low cost colorimeters and spectrophotometers appear to have errors (either systematic or drift errors) of up to 2 – 3 ΔE. Some devices have error in the near white, others in the near black. Note that if a device (a colorimeter in particular) was optimized or calibrated for non-D50 displays such as D65 at the factory, the errors in the vicinity of D50 may be significantly larger than the random noise of the device.

For some of these devices, the device to device variability is much higher than the random noise of each device. Colorimeters or spectrophotometers for use in a virtual proofing system must be calibrated to a defined standard such that the accuracy of the device relative to the standard is comparable to the error due to noise and random measurement error of the device. Calibrating the device to a reference standard can be achieved via accurate manufacturing procedures or can be performed external to the device via software look up table correction. The requirement for the measurement device for virtual proofing is to have a repeatability of +/-0.1 $\Delta E$ and an absolute accuracy of +/- 0.5 $\Delta E$ for all color values, particularly in all regions of white, gray, and black. More details on methods for correcting systematic measurement device error can be found in the patent literature (Edge, 2005).

**Stable, Uniform Illuminated Viewer for Hard Copy**

Since virtual proofing may require a side by side visual comparison with either a press sheet (in the case of press-side virtual proofing) or a contract CMYK hard copy proof (especially in the early adoption phase of prepress), an accurate, illuminated viewer is necessary. Note that D50 light booths historically have demonstrated variability with regard to color temperature. However, since proofs and press sheets are compared under the same lighting, and since light booths are almost never placed side by side for comparison, this variability has not been an issue. To a large degree, human perception adapts to the differences in color temperature and defines the current viewing condition as "white" when viewing images of snow, white lace, etc.

The challenge of virtual proofing is that the display device is required to simulate both the effects of the light booth as well as the paper and color properties of the hard copy proof. When a virtual proof display is adjacent to some form of light box or controlled illumination, slight differences between the systems are readily apparent. This problem can be handled by selecting an illumination that is:

- Uniform in intensity across the region where the hard copies are being viewed
- Contains light bulbs or fluorescent tubes that adhere well to the ISO specification for D50 viewing, are consistent over time and from lot to lot

The required accuracy for this consistency is such that the total variability is $< 1\ \Delta E$ from the targeted Yxy value (D50 is the standard target, with chromaticity values xy = 0.3457,0.3585). Note that this is much tighter than normal practice. KPG has found that it is very helpful if solution providers of virtual proofing systems certify fluorescent tubes for use in virtual proof comparisons, particularly in prepress environments.

## Minimum Configurations for Virtual Proofing

The virtual proof requires at minimum a local workstation to process the image data file and display the images on the display system. Levels of complexity can be:

- Stand alone workstation – calibrated display system, illuminated viewer for hard copy (if hard copy is to be viewed). All software and color control reside on PC.
- Interconnected workstations – essentially the above supported by some form of network infrastructure for ease of file transfer and color management control.
- Server based solution – multiple workstation interconnected via a server acting as the intermediary. In this scenario, the software components for processing files and converting color data can be distributed. The generalized conversions, including RIPing and conversion to a standard RGB space can be performed at the server. The non-general conversions can be performed at each local workstation via local software in the form of a browser plug-in or other local application.

## Software System Architecture Required

In this section, the most complex and complete system is described for enabling remote virtual proofing. This is the server-based model described above. The simpler forms of this system mentioned above would be identical except that the core processing software would all reside locally on one system rather than separated into server and local browser. Thus a very similar functionality could obtain by combining a viewer plug-in application with a standard annotation application such as Adobe™ Acrobat™. The management of the images could be performed using a variety of standard image database packages such as provided by Quark®, Cumulus®, etc.

The first section below, 3.2.1, describes the basic infrastructure of a system that is adequate for soft-proofing. The next section 3.2.2 describes the additional modifications required to permit a soft-proofing architecture to support virtual proofing.

## Database for Storing Page Image Files and Metadata

Most image databases provide standard features such as the ability to search by various fields such a job name, image name, customer name, date, etc. as well as the ability to view small thumbnail versions of each page. By their very design, databases permit “metadata” or data associated with each page, to be archived and retrieved easily.

### Upload/Download

For a distributed system, a simple means of transferring image files to and from the server is required. Most databases permit metadata to be indicated at the time of upload. In the case of KPG RealTimeProof system, for example, the metadata is associated with the destination "folders" which can be designated as workspaces, jobs, files, versions, etc. In general, the only requirement is that the metadata be easily indicated and retrieved.

### Page File Interpreter

The local or remote system must have the means to interpret and process the necessary image file formats. Most commonly, some form of raster image processor (RIP) is incorporated into the system. The CMYK image data and vector commands are converted to a CMYK bit map. Alternatively, the image data and vector commands can be converted to CT/LW format.

### Processing Parameters

Each file or job processed by this system must have a set of parameters associated with it. Some soft proofing systems allow the user to set resolution as a parameter while others allow color CMYK proof simulation to be set by selecting a CMYK ICC profile. Note that most high-end CMYK proofing systems allow both to be set.

Examples for setting processing parameters in a virtual proofing or digital contract proofing system are:

- Provide a menu of predetermined sets of parameters such as resolution, proof color simulation, etc. in the "Print" Window from the page layout application when printing to the proofing system
- Provide a setup window for each hot folder into which files or jobs are loaded or uploaded
- Provide a setup window from the client side whenever a job or file is uploaded

Once processing parameters have been set a means of verifying the parameters after the fact must be provided. In the case of hard copy output, it is desirable to indicate on the border of the proof the setup conditions used. In the case of virtual proofing, metadata must be retrievable for each proofed image in the database to ensure that one can later determine the parameters used for processing and displaying the file.

### Viewing of Images from Multiple Nodes on the Network

If performed locally, virtual proofing can consist of a feature similar to "Print Preview" used by most image and page editing applications. If multiple PC's are on a network, a simple file transfer can suffice. If viewing and annotating are required, "Print Preview" in the context of standard applications such as Adobe Acrobat could in theory be used. However, if proof color consistency is critical, and if the file is being viewed at different workstations at different times, there has to be lock-out mechanism to ensure that all participants can only view the color one way when performing such a "Print Preview" function, defined by the Administrator. Although this scenario is possible in theory, I am not aware of any such product on the market today.

If the mechanism used to perform virtual proofing is a server-based model, then a means of viewing the image must be provided. Since browsers are not optimized to view high-resolution images, client applications can be a very convenient way to view images that reside on the server, i.e. to utilize data compression and tiling to send only the necessary high resolution data as users zoom in and out of a high resolution image file. This is the approached used in RealTimeProof and Matchprint Virtual proofing systems.

The value of the server-based approach is that multiple users can access files at the same time or at different times from the same server and database. The central server is not used to display imagery – rather, all displaying of images is performed remotely via browser and client software.

### Password Protected Annotations

Solutions such as RealTimeProof and Adobe® Acrobat® offer the feature of password protection combined with annotation. For convenient differentiation, each participant who is making comments and annotations can have both a unique password and color for the annotations performed. Along with color, each annotation has a label with the individual's name to indicate which participant made which comments. In addition to uniquely identifying each participant, it is essential for virtual proofing to have a simple calibration state indicator (such as a large green check mark) to confirm that annotations were or were not performed in a critical color state. For example, legal comments can be performed on a non-color critical platform such as a laptop since the subject matter does not relate to color. A "non-critical color" indicator such as a red "X" in the annotation note is very helpful to reinforce how the image was viewed.

### Requirement for Selection of CMYK Profile

Each page, job, or groups of jobs needs to have a designated CMYK proof simulation.  The administrator for the page needs to choose which ICC profile is associated with the page.  This can be done via attaching an ICC profile for file-based virtual proofing. In this arrangement, the CMYK simulation must be password protected in a manner similar to annotations.  Furthermore, the application for viewing the image must honor the preset CMYK profile which has been attached to the file. When annotating, some means of confirmation must be added to ensure that all the correct setups were used for viewing the image on screen.

For remote virtual proofing using the server based solution, the CMYK simulation is set as a process parameter for the job by the administrator, using password access.  Non-administrators can view and confirm which color simulation was chosen for the job, but are not allowed to modify the choice.  This arrangement ensures flexibility and complete control. The advantage of this architecture is that multiple users can view at different times and annotate at their convenience in a color controlled manner.  This scenario permits current practice using hard copy proofs, where proofs are marked up at a particular location and time, and sent back to the originator of the proofs.  Unlike hard copy proofing, however,  virtual proofing also allows remote participants to view color and view annotations simultaneously.

A convenient way to allow the Administrator to set the color target is as follows:

- Preferences or Process Parameters for hot folders are accessed by the Administrator.
- The list of CMYK simulations are displayed in a menu and set by the Administrator along with other settings such as resolution.

Note that the CMYK simulations which reside at the server can be in the form of ICC device links (CMYK->RGB) generated from the source CMYK profile (which accurately characterizes the proofing condition to be simulated) and converting to a standard RGB space.  An example good choice for the RGB space is AdobeRGB98 (also known as SMPTE-240) with the white point set to D50 rather than D65.  This latter requirement ensures that conversions will be correct going from CMYK profile to the RGB space using absolute colorimetric rendering.  Note that absolute colorimetric rendering is required for retaining the appearance of paper base.

These links are listed according to their CMYK proofing names at the browser when process parameters are determined for a job or group of jobs.  At the server, the process is:

- CMYK files are interpreted and converted to a CMYK bit map, CT/LW etc.
- CMYK map is converted to the RGB data for SMPTE-240.
- Remote browser requests access to image
- Server transmits compressed RGB image data
- Plug-in or local client at browser decompresses RGB data
- Plug-in or local client at browser converts SMPTE-240 RGB data to local display RGB data via local CMM and RGB system profile
- Plug-in or local application at browser displays RGB pixels on the screen

**Optimal Scaling and Sharpening**

In order to give the appearance of sharpness, contrast, and detail, the RGB data rendered on the display device should be dynamically sharpened. This combined with any necessary colorimetric corrections will account for flare and pixel resolution.

When high-resolution CMYK hard copy proofs are compared with a virtual proof generated from the same file, sharpening must be applied when the image is viewed in a 1:1 ratio with regard to the physical size of the image. As a higher zoom ratio is used, less sharpening (or none) is required since the rendering of the image detail is now visually equivalent between hard copy and virtual proof.

The means of applying the sharpening is flexible: for example in the server-based solution, the sharpening can be applied at the server or at the browser level via plug-in or browser launched local application. It is desirable for simplicity of architecture to apply the correction locally, thereby making the system more flexible as newer display devices are added as optional means of viewing the virtual proof. The degree and nature of the sharpening will almost certainly be different for different display devices, in particular for a CRT vs. an LCD at 100 dpi. For further details on scaling and sharpening for virtual proofing can be found in the patent literature (Edge, 2002b)

**Indicator of Measurement CIELAB Values**

The virtual proofing system described in this document must provide an eyedropper tool with the following characteristics:

- Displays the original CMYK pixel value when the tool is pointing toward a particular pixel location in the displayed image
- Displays an accurate prediction of the measured value of L*a*b* along with the value of CMYK. This value should be consistent with a particular specified device such as a Gretag SPM50 at D50 illumination, 2-degree observer. This value should be calculated

and displayed to an accuracy of at least one decimal place, i.e. should read L*a*b*=(97.5, 0.3, -0.2) rather than L*a*b*=(98, 0, 0).

The reason for displaying the measurement predicted value is to permit a press operator to measure a specific color to confirm whether it matches the L*a*b* color value intended by the originator of the image file.

**Control of Image Viewing Regarding System Warm-Up**

A final control mechanism required in a virtual proofing system is the assurance of an adequate warm-up time. Internal studies have shown that CRTs and LCDs often emit much brighter or dimmer light when first switched on, and then remain very stable for long periods of time once temperature stability is achieved.

To address this issue, the virtual proofing system must have a local startup application that detects whether the system has been shut down and rebooted. The time of reboot can be used to determine warm-up time. This startup application can have several means of preventing the premature use of the system:

- The startup application can create a time stamp file that is read by the browser image viewer application. The viewer application will not permit images to be viewed in "color critical mode" until the appropriate warm up time has occurred
- The calibration application can prevent calibration from occurring before warm-up has occurred
- The startup application can launch the calibration application. The calibration app can then alert the user that warm-up must occur. Meanwhile, the user can position the measurement device on the display and leave the system. After the specified warm-up time, the calibrator can automatically proceed to measure, validate and/or recalibrate the display.

For convenience, the startup application can be configured to ignore reboots if they occur shortly after shut down (e.g. five minutes) since the display will still be in the warmed up state. Generally, after a cold shut down and reboot, it is desirable to run the measure/validate/calibrate procedure to make sure the system has returned to the correct state and correct it if it has not.

As an extra precaution, the startup application can run continuously in the background and periodically communicate with the display via protocols such as VESA specified ddc/ci to ensure that the display is in fact on and functioning.

## Conclusion

The virtual proofing system described above will have the following beneficial properties:

- It will render CMYK images to a CRT or LCD screen so accurately that the user will feel that they are viewing and interacting with a hard copy image
- The system will ensure consistency between CMYK images viewed at multiple locations and over time
- The system allows flexibility to the Administrator to determine what proofing color target is being used for jobs that are viewed at multiple locations
- The system forces calibration before at regular intervals
- The system minimizes risk by eliminating common causes of color variability on a display, including warm up time, forgetting to calibrate, etc.

These attributes are unique to a true virtual proofing system. Other features common to soft proofing systems such as annotations, upload/download, etc. are of course required as well. However, without the properties listed above, a soft proofing system alone may not be able to support true virtual proofing. Further details on the requirements and options for a virtual proofing system can be found in the patent literature (Edge, 2003).

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