Quality managed proofing: The road to visual consistency*

Stefan Livens and Marc Mahy

Keywords: proofing, quality, control, calibration

1. Abstract

In this publication factors are evaluated that determine the color consistency of a digital contract proofing system. Based on these factors, a complete quality control approach, called “quality managed proofing”, is presented. This is achieved through three main steps. A calibration step offers the tools to bring a proofer into a standard condition, for which a predefined tonal response can be guaranteed. A proofer verification module enables the user to monitor the behavior of the proofer's output. It points out problems and also prompts the user to perform suitable actions in order to restore the quality. And finally, a proof verification module that compares the proof with the final print as well as with the target that can be an ICC profile or a dedicated standard printing process.

2. Introduction

In the past few years, there has been a quite fast move from conventional to digital proofing systems due to the introduction of computer to plate (CTP) systems. As CTP systems do not use film anymore in the plate making process, digital color separations have to be used to make proofs. Hence, the proofing workflow moved from the conventional approach based on films to a complete digital printing approach. Although, digital color separations were already in use in the graphic arts market for some time, their use in proofing was not widely accepted until recently. As proofs are used as the main quality check in print runs, the accuracy, consistency and quality of a digital proofing workflow has to be as good as its conventional counterpart to be accepted in the market.

In this publication, the color reproduction approach of a digital proofing system is discussed. First of all a calibration procedure has to be defined. Such a procedure not only guarantees that a given system is stable over time, but it also has to ensure that the same colors are reproduced on different devices of the same type. In a second step, the printing system is characterized by making use of ICC profiles[1]. Typically, the printing process is modeled with an output profile whereas the proofer is characterized with a proofer profile. All information presented in this article is based on an inkjet system dedicated for proofing.

As the main purpose of a proofing system is to simulate a given printing process, the quality of the proofing device can be directly determined by measuring its ability to reproduce standard printing processes. The success of color proofing depends crucially on two factors. Firstly, the proofer should produce reliable results, meaning that for a given input always exactly the same, well-defined output is generated. Secondly, a color managed workflow should be applied correctly using consistent output and proofer profiles.

The accurate reproduction of colors is seen as one of the most important characteristics. The demands for consistent and predictable color quality are very high, since in contract proofing a precise rendition of colors is pursued. This makes contract proofing much more color critical than most other printing applications where one is mainly concerned with producing pleasing images. Moreover, the quality in proofing is generally judged by the worst match encountered.

Because a proofing system has to provide highly reliable color reproduction, this output needs to be controlled very accurately. Therefore it becomes a necessity to have a quality control system so that users not only can calibrate and characterize their device, but that it is also possible to check at any time the accuracy of the color reproduction process.

When a predefined tonal behavior can be guaranteed over time, it becomes possible to create identical proofs over and over again. This color consistency eliminates the need for making new profiles that compensate for temporal changes. If a common condition can also be enforced for different proofers at various locations, consistent proofing can be obtained everywhere. As a result, several printers can share the same profile what simplifies the workflow.

* Presented at the 29th International IARIGAI Research Conference, September 8-11, 2002 Switserland.

Remote contract proofing relies completely on the ability to precisely define and control the output at different locations. Without a predefined and guaranteed condition of the remote proofer, it is impossible to obtain consistent good results. An automatic monitoring of color quality is essential because the remote side normally does not know what output is expected.

Given all this, it is clear that in order to achieve consistency, it is essential to control the proofing system as a whole[2,3]. We therefore propose a complete solution, called quality managed proofing, that consists of three modules. A calibration module comprises all tools needed to bring the proofer into a standard condition, hereby guaranteeing a predefined tonal response. A proofer verification module enables the user to monitor the proofer output (without color management) and compare it with the standard condition. Finally a third module, called proof verification, checks the correspondence between the color managed proof and the final print. If during one of the verification steps an error is detected, the user is warned and prompted to perform suitable actions in order to restore the consistency.

3. Color management

In most conventional proofing systems, color reproductions are made based on separations on film. These systems used the film separations of the printing process that has to be simulated. Hence conventional proofers were designed to simulate a given printing process, mainly by optimizing the medium and inks for that printing process.

In digital proofing, the separations of an image to be reproduced are exchanged digitally. These separations correspond to the medium and ink combination of a given printing process and hence they are in general different from the inks and medium used by the proofer. Moreover, colors on inkjet systems are in most cases rendered in a different way than for most other printing processes such as offset and gravure. This implies that the separations corresponding to the printing process cannot be used by the digital proofer directly. Therefore, the separation values have to be converted to the proper ink values of the proofer so that the same color can be reproduced.

A practical system in which colors can be transformed properly from one color reproduction device to another one is given by the International Color Consortium (ICC). In this system, each device is modeled separately by a number of transformations from device dependent color values to device independent color values and vice versa. For a CMYK printing process, there are both transformations from CMYK to CIELAB or XYZ as from CIELAB or XYZ to CMYK. If colors have to be transformed from one system to another system, a transform from the device dependent color space of the first system to a device independent space is coupled to a transform from the device independent space to a device dependent space of the second color reproduction system.

Within ICC four different transforms have been defined, also referred to as rendering intents. These rendering intents are optimized for a given workflow. In scanning for example in most cases the perceptual rendering intent is used whereas the colorimetic intent should be used if colors have to be reproduced exactly. The four rendering intents defined by the ICC are: the perceptual, the absolute colorimetric, the relative colorimetric and the saturation match.

In proofing there are two main workflows. Either photographic images are provided or digital files are delivered for a given printing process. In the first case, the images have to be scanned and transformed to the printing process. In a second step they are converted further on to the proofer color space. In the second case, the images can be converted immediately to the proofer space.

For the first workflow, three profiles are required; i.e. the scanner profile, the output profile and the proofer profile. The rendering intent for the transform from scanner RGB space to the printer CMYK space has to be the same and in most cases the perceptual intent gives the best results. If artificial images are used, more saturated colors will be obtained with the saturation match. The second transform from printer CMYK space to the proofer CMYK space should be the colorimetric intent. If the colors have to be reproduced exactly, the absolute colorimetric rendering intent should be used. If however, colors are judged compared to the paper white, the relative colorimetric intent provides the proper color transform.

For the second workflow, only the output and proofer profile are needed that are used both in the colorimetric mode.

Hence to support both workflows, the minimum required tables for the output profile are the perceptual, colorimetric and the saturation intent in case of output profiles and the colorimetric intent for the proofer profile.

Apart from providing different rendering intents, it is also required to give the user control over a number of separation parameters for the output profile as required in the graphic arts market. Typical examples are global ink limitations, the maximum amount of the black ink and a number of GCR settings. In case of the proofer profile, almost no separation values are normally provided to the user, but the separation and the mapping of out-of-gamut colors are in general optimized for type of inkjet technology, the inks and the medium. Hence, the user needs an application that generates profiles optimized for a given proofing device.

4. Calibration

The variables that influence the printed output cannot always be controlled with the required precision. In order to compensate for the changes, a calibration is needed. The goal of the calibration is to bring the printer into a standard condition. A calibration typically includes printing a set of one-ink patches. The resulting measurements precisely describe the ink behavior on paper of the separate inks. By comparing these color values to the desired reference tonal behavior, calibration tables can be calculated. Calibration encompasses ink limitation and linearization. When multi density inks are involved, which is common in high quality inkjet printing, also ink mixing should become part of the calibration process.

4.1 Ink Limitation

In general inks are limited in two different ways; i.e. global limitations or limitations per ink. Global ink limitations, governing the amount of all inks together, are best controlled in the profile making step. Limitations on individual inks on the other hand are part of the calibration step and in reality they serve a double goal. The first goal is that of calibration: ensuring that the printer is in a standard condition. Printing a solid at the maximum level of ink should yield a fixed result. This can be obtained if the percentage is significantly less than 100 %, other wise there is no room for adjustments. Apart from this, many printing artifacts can be reduced or avoided if the maximum ink percentage is less than 100%.

4.2 Linearization

While the printed output for the maximum amount of ink is already fixed by the ink limitation, the tonal behavior for all intermediate values can still vary. This can be solved by regularization, which is the construction of a calibration function in such a way that a fixed correspondence between the image data and the measured quantities is obtained. The correspondence does not necessary have to be made linear. However, there are distinct advantages to linearity, e.g. regarding stability and optimal use of available levels. This explains why regularization often equals linearization, and the latter has even become the common term for the general process.

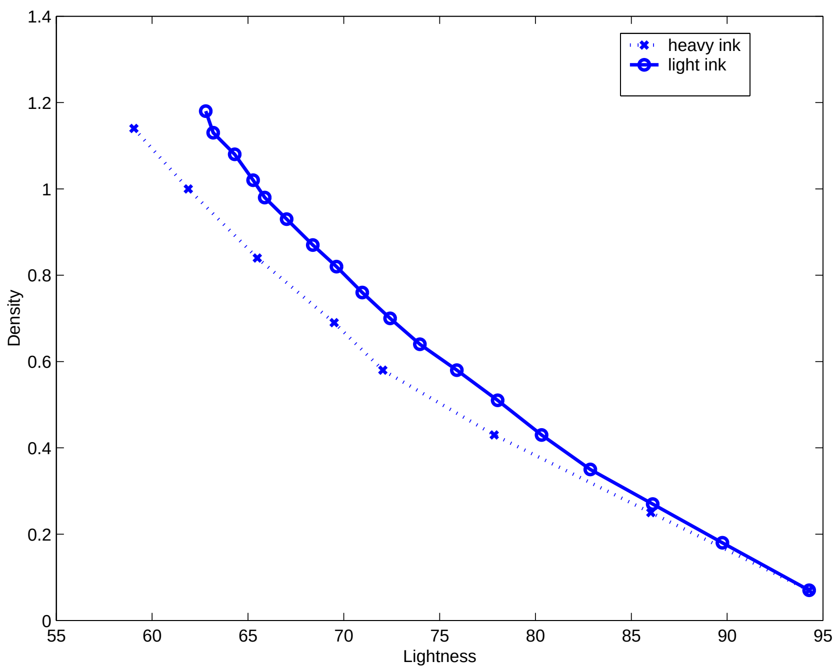

Figure 1: Density versus Lightness for different percentages of heavy and light cyan ink.

4.3 Quantities

Calibration necessarily has to relate to measurable quantities. The question arises which quantity should be measured. Traditionally, measuring density has been common practice. While this is very useful in relation to printing presses, it is much less useful for proofing on inkjet printers. The spectral properties of inkjet inks are not the same as those in the final print. Since pure colors in print are not pure colors on the proof, comparing densities across processes makes no sense.

When multi-density inks are involved, measuring densities becomes even less advisable. Dot area comparisons between proof and print become meaningless. Also, there no longer is a simple one-to-one correspondence between the visual quantities and densities. This is illustrated in fig.1 by plotting the densities of step wedges printed with light and heavy cyan. For the same lightness, the measured densities are different for the two inks.

Since proofs are designed to match visually, a quantity related to visual perception is preferred. Common availability of spectrophotometers allows using CIELAB. Lightness is the most convenient quantity for cyan, magenta and black ink. Chroma is preferred for the yellow ink for accuracy reasons as the lightness range between paper white and solid yellow is too small.

4.4 Multi-Density Inks

Many modern inkjet printers extend their ink set beyond CMYK and include extra inks. These can be completely new colors, such as a green, blue or orange ink, resulting in a wider gamut. In most cases however an additional light cyan and light magenta ink are used. The main purpose is to improve the apparent resolution. The light ink is used in the highlights, where it results in less visible dots. In the darker regions, heavy ink is used so that the total ink amount does not increase too much.

A traditional separation into CMYK does not suffice for printing with such a printer[4]. Because the light and heavy inks are similarly colored, and for compatibility with existing standards and software, the separation is normally implemented as a two stage process[5]. The first stage is a normal CMYK separation. The second stage corresponds to the ink mixing; i.e. the transformation of the ink percentages into percentages of light and heavy ink.

Several criteria for a good ink mixing have been identified: avoid objectionable dot patterns, have smooth color gradations in vignettes and avoid using too much ink[6]. The main issue can be summarized as *How to mix without creating artifacts?* Various proprietary methods are being used for ink mixing. Often the process is transparent to the user, or at most a global control of the amount of light ink is offered.

Ink mixing offers additional degrees of freedom compared to single density printing. These can be exploited in order to improve the output in several ways[4]. A detailed study of the optimization of ink mixing appeared in ref. 7. Experiments show that it is possible to control the hue shifts between light and heavy inks, which in turn allows printing with less visual artifacts resulting in smoother and more stable vignettes.

To our knowledge, until now ink mixing has always defined in a fixed way, by imposing constraints on the ink percentages of light and heavy inks, independent of the calibration. In our proposed solution, the ink mixing characteristics are defined in measured quantities and the ink mixing is being calibrated. The importance of this approach becomes can be explained as follows. A fixed ink mixing can be optimized for a certain condition of the printer. However, the behavior of the printer can vary over time, and the variations can be different for the light and heavy versions of the ink. Calibration acting only on the primary CMYK inks cannot compensate for this in an accurate way. The incomplete compensation results in an ink mixing that is no longer optimal. Only if the ink mixing is incorporated into the calibration, visually optimal ink mixing can be achieved at all times for the real conditions of the printer.

4.5 Setting Calibration Targets

For a given combination of inks, printer and medium, we define the standard condition by fixing a standard tonal response. For some applications, it is necessary that the user can define custom tonal responses for specific media and/or settings. A good example of this is newspaper proofing, where proofs are often made on stock paper.

Choosing ink limitations is far from trivial. Visual artifacts such as bleeding most often become more prominent with increasing ink levels. Often, putting more ink on paper does not offer any advantages beyond a certain point. Sufficient headroom needs to be provided in order to allow compensation of print variations. On the other hand, ink limitation should not be too drastic as it reduces the resulting gamut. Information regarding all of these issues is important for making good ink limitation choices.

A problem lies with the visual artifacts as these are normally evaluated by visual inspection of prints. This can become very tedious if the evaluation has to be repeated for many different ink limitation settings. We propose an alternative for this. The procedure is similar to that of calibration. A special target containing many patches is printed and measured colorimetrically. From these measurements, a prediction is made for the gamut and bleeding characteristics of the paper for all possible ink limitation settings.

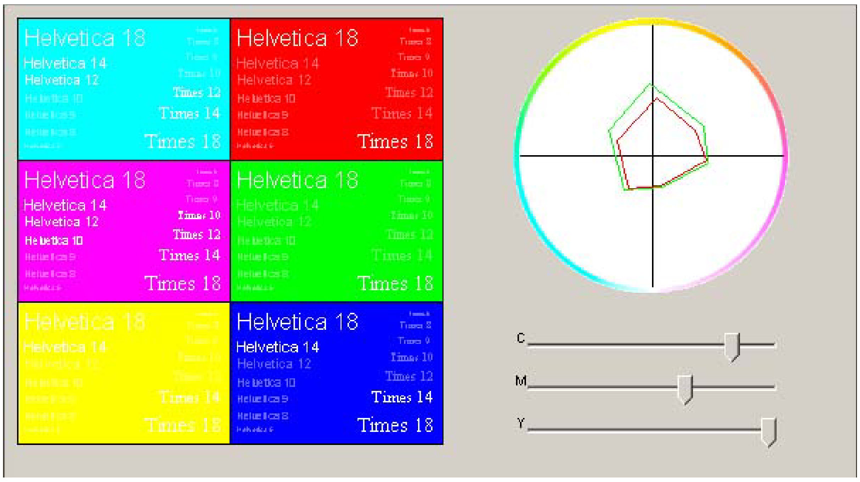

Figure 2: On the left, the effect of bleeding on negative text in various colors, sizes and typefaces is visualized. On the right, the gamut is shown in comparison with the gamut of a standard process.

The results are presented in a way that is easy to interpret with a user interface as shown in Fig. 2. The gamut is visualized as a projection on top of the gamut of the printing process that is proofed. The bleeding is presented as a visual acceptance scale with negative text in primary and secondary colors shown in various sizes and typefaces. The user can interactively change the settings and immediately sees the results on screen. An underlying wizard verifies if the chosen settings are valid and corrects them if necessary. This system gives the user the best tools for making a guided choice in the trade-off between gamut and visual artifacts.

Once a choice has been made, the associated tonal responses can be saved to file. From that moment on, this file is always used as the reference condition for a particular combination of ink, medium and printer settings. The calibration will target to its tonal responses, and the verification (as described further on) will compare the actual output with the reference.

5. Proofer verification

5.1 Goal

The second module is the proofer verification step . It checks if the proofer is printing in the way as targeted by the calibration. In order to be successful in practice, the required effort needs to be kept minimal. This is the main reason for having a specific verification apart from the calibration. It would be too great a burden to recalibrate the printer every time consistent quality is needed. A small control strip was defined in accordance with ISO 13656[8]. Printing and measuring such a strip requires only a small effort. The integration with the rest of the software ensures that settings can be automatically controlled and logged.

5.2 Sources of Variation

We assess the various factors of variation and estimate their impact on the output. As it turns out, many variables, both system and environmental ones, can cause significant changes in the output. Inkjet technology, like most other printing technologies, makes use of mechanical and electrical components and chemical substances. The mechanical parts can differ from printer to printer, they are subject to wear and tear and possible failure, as are the electrical parts.

The ink, as a chemical substance, will change its interaction in a certain way when changes in the environment occur. This makes inkjet printing especially vulnerable to changes in conditions such as temperature and humidity. Ink replacements can also have a profound impact on the output. This is also the case for the medium, which is equally crucial to the resulting output. Changes can occur even between different batches of supposedly identical medium. It goes without saying that real alterations to ink or medium, either deliberately or by mistake, will also cause different outputs. The same is true for the various settings of the printer and all software involved.

A well-known problem in inkjet printing is that nozzles of the inkjet head can gradually clog up due to drying ink. Cleaning heads regularly solves this problem, but the output cannot be guaranteed to remain identical at all times. The rapid evolution of inkjet technology results in ever increasing quality of outputs, but at the same time, printing requires higher precision components and the challenges for consistency grow.

5.3 Detecting Problems

Various causes of print variation are already mentioned in the previous sections. However, the effect of time still has to be added. Ink typically needs to dry for some time before a stable color is obtained. On the other hand, inkjet prints are often subject to aging effects, especially due to fading. This makes it necessary to use fresh printouts, and never to compare new printouts with archived ones. Both effects call for strict operational procedures to ensure that a fixed time is strictly observed before measuring a printout.

Before we can detect problems, we have to quantify the variations of a normal stable operation. Statistical description and analysis of the variability of printing presses has been given some attention, as presses are known to vary quite considerably[9]. For inkjet proofing, there are very few published results.

Using the terminology of statistical process control, the normal printer variations determine the process capability. This indicates the attainable consistency. The ultimate goal of color control in proofing is to create proofs that are visually indistinguishable. This determines the desired consistency, which translates into (upper and lower) control levels. If the attainable variability is larger than the desired one, perfect matching proofs cannot be guaranteed. With modern technology and given sufficient care, both are comparable in magnitude.

The natural variations are usually small but cannot be avoided. They stem from the measurement itself (physical measurements unavoidably contain some uncertainty), or from normal print variations. They typically vary from one print or one measurement to the next, and should not be corrected for by calibration. Trying to correct them is doomed to fail, as a correction based on the deviation in one print is already invalid for the next print. Such unnecessary recalibration is in fact overcorrection. It increases the variation in the printed output and causes stable systems to deviate more than they would when left alone[10].

The key to the detection of problems is the choice of tolerance levels based on the control levels. Once the tolerance levels are fixed the detection of problems can become an automatic procedure. In order to establish tolerances, we collected a large amount of experimental data over a month's time. Along with the measurement data, we kept rigorous track of all factors that might influence the printed result. In the analysis of this data we were able to correlate the measured variations in the output with different events in the external factors. It turns out that different external factors correspond with variations in the printout that are distinct in direction and magnitude.

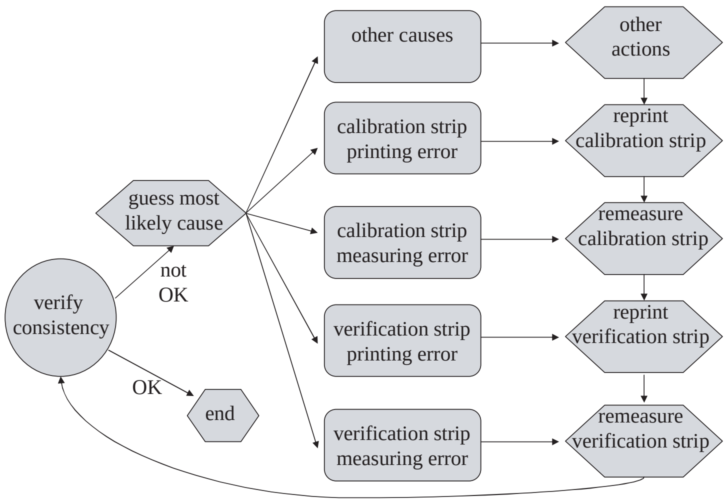

Figure 3: Partial diagram showing the hierarchy of problems and corresponding actions.

5.4 Solving Problems

The fact that we can differentiate between various types of problems is crucial. A problem can only be fixed if its precise cause can be identified. Therefore, it is very important that the tolerances are determined very precisely. Only then, various causes can be distinguished by evaluating the direction and magnitude of the measured variations.

We have developed a knowledge based system that identifies what causes most likely correspond to what variations. It also takes into account the effort required to fix the problem, given its cause. It uses the following logical principle: *maximize the chance of fixing the problem with the minimal effort necessary*. This results in a cascading system. The actions can more or less be ordered hierarchically according to the effort required to perform them. An initial guess is made of the most probable causes.

The best action to attack the problem is determined from these causes, also taking into account the effort of the solutions. When two causes are equally probable, the one with the corresponding action on the lowest level is suggested first. After this correction has been tried, the new result is evaluated. If the deviation is not solved, a new action on a higher level is suggested. For this, the most probable cause is determined, based on the new results, taking into account the experience of the first cycle. The process can be repeated as long as necessary.

A partial view of the common sense reasoning followed by the system is shown schematically in fig. 3. We illustrate it from an example. If the readings of the complete verification strip are out of line in a certain way, perhaps the strip was measured wrongly. Then, the best guess is to remeasure the strip. Since there is no evidence that it needs to be reprinted, the action requiring less effort is preferred.

If a single patch shows a deviation the patch perhaps got damaged, e.g. by dirt or a fingerprint. In this case, remeasuring the strip cannot solve the problem, we need to go to a higher level and reprint the strip first. If this would turn out to be ineffective, there must be a real deviation of the printer. If there is no compelling evidence that points to a certain cause of the deviation, the system will suggest recalibrating. Again, if there remains a problem, remeasuring or reprinting of the calibration strip is considered depending on the deviation.

If none of the solutions can bring the printer into a standard condition, higher level actions are proposed such as checking if the medium is correct, cleaning printing heads, etc. If all else fails, the system might resort to suggesting having the printer serviced.

The advantages of having such a cascading system are very clear. The user has a systematic approach at hand for solving his problem. The deviations encountered are interpreted by the system in the best possible way. This increases the chances of directly attacking the problem at the right level, so that many useless tests can be skipped and time is saved. The servicing engineers will only be called in when all other efforts have failed. They can directly look into the data recorded during the previous tests, which also helps them in their work. They also have access to the rest of the recorded history of the printer.

6. Proof Verification

In the proofer verification module, we manage the consistency of the proofer as such, independent of the process it simulates. Therefore we investigate prints using calibration but without the use of color management transforms. This system of calibration and verification is what we call "quality managed printing", and was described in Ref. 11.

For a complete control of the proofing workflow, moving up to "quality managed proofing", the color management part of the proofing solution has to be controlled as well. Therefore, additional verifications need to be provided in order to maintain the consistency of the output and proofer profiles.

The first is the print to reference verification. It makes use of customary press control strips present on final prints (not proofs). Measurements of the control patches are compared with a reference. Such a reference can be a dedicated output profile or a print standard. The comparison reveals the consistency of the print to the reference. The setting of suitable tolerances is again a very important issue. Fortunately, we can now rely on standards such as ISO 12647[12].

The second is the verification of the proof against the reference. Again a control strip is used. This is usually similar, but not necessarily identical to the previous control strip. The control strip is still specified using CMYK values of the simulated printing process. However, now it is simulated on the proofer, meaning that it has run through color management and outputted using a calibrated inkjet proofer. Given a consistent proofer, this test reveals the consistency of the color management, thus of the combination of proofer and output profile.

7. Conclusion

Consistent color quality can only be achieved by controlling the proofing system as a whole. A complete solution was proposed under the term “quality managed proofing”. An important part of the solution is “quality managed printing”, which deals with the control of the proofer.

Quality managed printing relies on two modules.

The calibration module contains the tools needed to bring a proofer into a standard condition, for which a predefined tonal response can be guaranteed. Besides taking care of ink limitation and linearization, it has the unique feature that it explicitly takes ink mixing into account. This leads to improvements in the output, especially for smooth vignettes. For the definition of standard conditions for custom media, a system was proposed that helps the user in making guided choices based on information about gamut and visual artifacts.

The proofer verification module verifies if the proofer output still complies with the standard condition. It points out problems and also prompts the user to perform suitable actions in order to restore the quality. For these actions, a cascading system guides the user in performing the right action to solve the problem with the least effort possible. The system proposes solutions and not just signals problems which makes it much more valuable in practical use.

To obtain a complete quality management system for proofing, a proof verification module is added. This module verifies the consistency of color management by means of two independent verifications. In a first verification the output profile is checked by comparing measurements of a press control strip on the final print with a reference. The second verification simulates a comparable strip on the proofer, and compares to the same reference.

8. Literature

1. Specification ICC.1:2001-12, File format for color profiles (Version4.0.0), see http://www.color.org.
2. D. Toth, “Proofing makes the workflow flow", Graphic Arts Monthly, vol. 73, no. 8, pp. 30-36, 2001.
3. Wandelt
4. S. Tominaga, “Color conversion using neural network", Proc. SPIE 3300: Color Imaging, Device Independent Color, Color Hardcopy, and Graphic Arts III, (San Jose, CA), 1998.
5. H. Zeng, “Ink limit control for inkjet color calibration", Proc. SPIE 4300: Color Imaging, Device Independent Color, Color Hardcopy, and Graphic Arts VI, (San Jose, CA), 2001.
6. Y. X. Noyes, J. Y. Hardeberg, and A. Moskalev, “Linearization Curve Generation for CcMmYK Printing", Proc. Eight Color Imaging Conf., (Scottsdale, Arizona), 2000.
7. S. Livens, “Optimisation of printer calibration in the case of multi density inks", Proc. First European Conf. on Color in Graphics, Imaging and Vision (CGIV'2002), 2002.
8. ISO 13656, “Graphic technology – Application of reflection densitometry and colorimetry to process control and evaluation or evaluation of prints and proofs”, 2000.
9. R. A. Siljander, and R. S. Fisch, “Accuracy and precision in color characterization", Proc. of TAGA, pp. 57-79, 2001.
10. J. Compton, “Measuring production variability", PrintRIT, no. 2, pp.7-9, 1994.
11. S. Livens, M. Mahy, “Optimization of printer calibration in the case of multi-density inks", Proc. SPIE 4663: Color Imaging, Device Independent Color, Color Hardcopy, and Graphic Arts VI, (San Jose, CA), 2002a.
12. ISO-12647, “Graphic technology –Process Control for the manufactur of half-tone colour separations, proof and production prints: Parts 1, 2, and 3”, 1996.