Consistent Inkjet Proofing with a Quality Management System

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Abstract: We explore the factors that determine the consistency of colour output on digital proofing systems based on inkjet technology and propose a complete solution called "quality managed proofing". This is achieved through three main modules. A calibration module offers the tools needed 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 behavioiur of the proofer's output. It points out problems and also prompts the user to perform suitable actions in order to restore the quality. A proof verification module compares the generated proof with the final print as well as with the target which can be an output ICC profile or a dedicated standard.

Introduction

In contract proofing, the behaviour of one printing process, e.g. a press standard or a particular press, is simulated on another process, e.g. an inkjet printer. Colour management solutions are able to carefully model both processes and specify the desired output in a device independent manner.

The success of proofing depends crucially on two factors. Firstly, the proofer should produce reliable results, meaning that for a given input it should always produce exactly the same, well defined output. Secondly, a colour managed workflow should be correctly applied using consistent proofer and output profiles.

The demands for consistent and predictable colour quality are very high, since a precise rendition of colours is pursued. This makes proofing much more colour-critical than many other printing applications where one is mainly concerned

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with producing pleasing images. Moreover, proofing quality is generally judged by the worst match encountered. This also stresses the importance of a very tight control on the printed output.

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

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 colour 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 (Toth, 2001) (Wandelt, 2001). We therefore propose a complete solution, consisting 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 colour management) and compare it with the standard condition. A third module called proof verification checks the correspondence between the colour managed proof and the final print and/or. As part of the verifications, the user is warned if significant changes occur. Additionally, he is also prompted to perfrom suitable actions in order to restore the consistency. A practical implementation of the proposed solution has been introduced as the *Agfa Quality Management System* (QMS). This software package has been integrated into the six-colour AgfaJet Sherpa digital colour proofing system.

Calibration

Goal of 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 out an set of colour patches. The resulting measurements precisely describe the ink behaviour on paper. By comparing this to the desired reference tonal behaviour, calibration tables can be calculated. Calibration encompasses ink limitation and linearisation. When multi density inks are involved, which is common in high quality inkjet printing, also ink mixing should become part of the calibration process.

Ink Limitation

The term ink limitation can have two different meanings. Total ink limitations, governing the amount of all inks together, belong to colour profile making. Ink limitations on individual inks are part of calibration and can 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 by adjusting the maximal percentage of ink. Apart from this, the maximum useful or wanted ink percentage is often less than 100%. Reducing the percentage as such becomes the second goal of ink limitation, as it is convenient to incorporate this into the calibration.

Linearisation

While the printed output for the maximum amount of ink is already fixed by the ink limitation, the tonal behaviour for all intermediate values can still vary. This can be solved by regularisation, which is the construction of a calibration function in such a way that a fixed correspondence between the image data and the measured quantities results. 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 regularisation often equals linearisation, and the latter has even become the common term for the general process.

Quantities

Calibration necessarily has to relate to measurable quantities. The question arises of 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 colours in print are not pure colours 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. We illustrate this 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. The lightness is the most convenient quantity for cyan, magenta and black ink. Chroma is preferred for the yellow ink because the lightness range between paper white and solid yellow is too small.

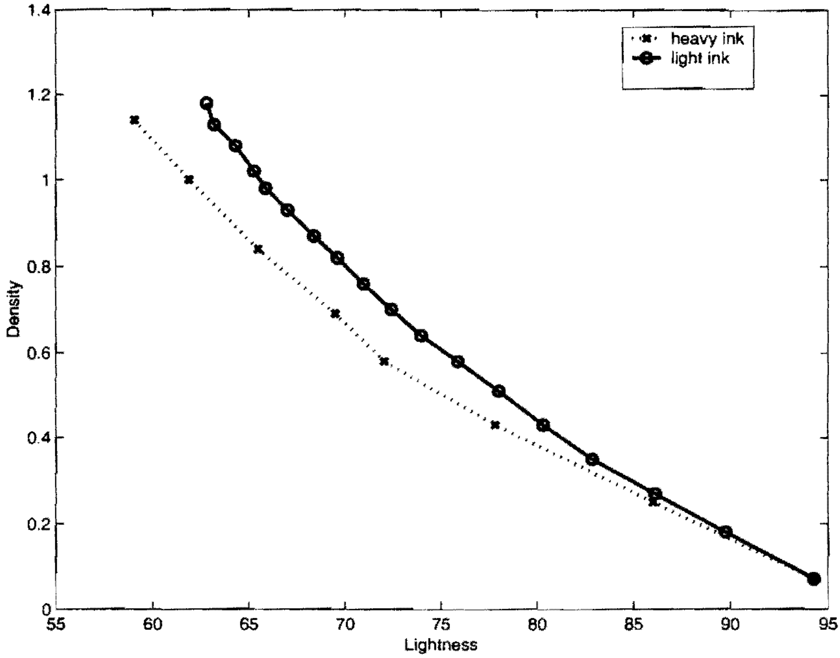

Figure 1: Density versus Lightness for different percentages of heavy and light cyan ink.

Multi Density Inks

Many modern inkjet printers extend their ink set beyond CMYK and include extra inks. These can be completely new colours e.g. a green or orange ink, which result in a wider gamut. In most cases however an additional light cyan and light magenta ink are used. The main purpose is then 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 use does not increase too much.

A traditional separation into CMYK does not suffice for printing to such a printer (Tominaga, 1998). Because the light and heavy inks are very similarly coloured, and for compatibility with existing standards and software, the separation is normally implemented as a two stage process (Zeng, 2001). The first stage is a normal CMYK separation, and the second the ink mixing, during which the ink percentages are translated into percentages of light and heavy ink.

Several criteria for a good ink mixing have been identified: avoid objectionable dot patterns, have smooth colour gradations in vignettes and avoid using too much ink (Noyes, 2000). The main issue can be summarised as *How to mix without creating artefacts?* 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 (Tominaga, 1998). A detailed study of the optimisation of ink mixing appeared in (Livens, 2002b). Experiments show that it is possible to control the hue shifts between light and heavy inks, which in turn allows to print with less visual artefacts which results in smoother and more stable vignettes.

To our knowledge, ink mixing is 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 becomes clear from the following. A fixed ink mixing can be optimised for a certain condition of the printer. However, the behaviour of the printer can vary over time, and the variations can be different for light and heavy versions of an ink. Calibration acting only on the primary CMYK ink cannot compensate for this in an accurate way. The incomplete compensation results in an ink mixing that is no longer optimal. Only when the ink mixing is incorporated into the calibration, visually optimal ink mixing can be achieved at all times for the real situation the printer is in.

Setting Calibration Targets

For a given combination of ink set, printer and paper type, we define the standard condition by fixing a standard tonal response. For some application types, it is necessary that the user can define custom tonal responses for specific paper types 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 artefacts 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 overly drastic, as this reduces the gamut. Information regarding all of these issues is important for making good ink limitation choices.

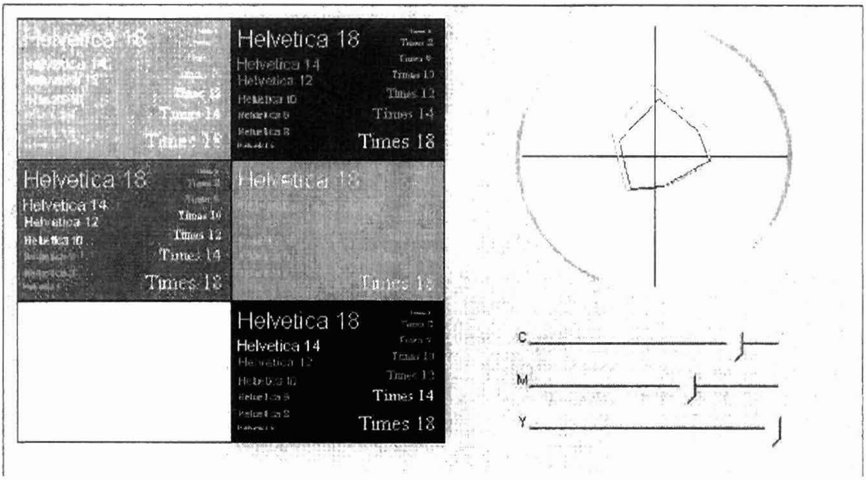

Figure 2: On the left, a visualisation is given of the effect of bleeding on negative text in various colours, sizes and typefaces. On the right, the gamut is shown in comparison with the gamut of a standard process.

A problem lies with the visual artefacts as these are normally evaluated by visual inspection of printouts. This can become very tedious if the evaluation has to be repeated for many different ink limitation settings. We propose an alternative to 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.

The results are presented in a way that is easy to interpret, with a user interface as shown in Fig. 2. The gamut is visualised 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 colours shown in various sizes and typefaces. The user can interactively change the settings and immediately sees the results on his 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 artefacts.

Once a choice has been made, the associated tonal responses can be saved to a file. From that moment on, this file is always used as the reference condition for a particular combination of ink, paper 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.

Proofer Verification

Goal

The second part of the solution is the proofer verification module. It checks if the proofer is printing in the way as targeted by the calibration. In order to be successful in practice, the required user effort needs to be kept minimal. This is the prime reason for having a specific verification apart from the calibration. It would be a too great burden having to recalibrate the printer every time a consistent quality is needed. A small control strip was defined in accordance with (ISO 13656, 2000). 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.

Sources of Variation

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

The ink, as a chemical, will typically change its interaction 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 paper, which is equally crucial to the output. Changes can occur even between different batches of supposedly identical paper. It goes without saying that real alterations to ink or paper, 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, 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, the printing requires higher precision components and the challenges for consistency grow.

Various causes of print variation were already listed. The effects of time on the print must be added to them. Ink typically needs to dry for some time before the final result is obtained. On the other hand, inkjet prints are often subject to ageing 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 (Siljander, 2001). 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 colour control in proofing is to create proofs that 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, completely 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 (Compton, 1994).

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.

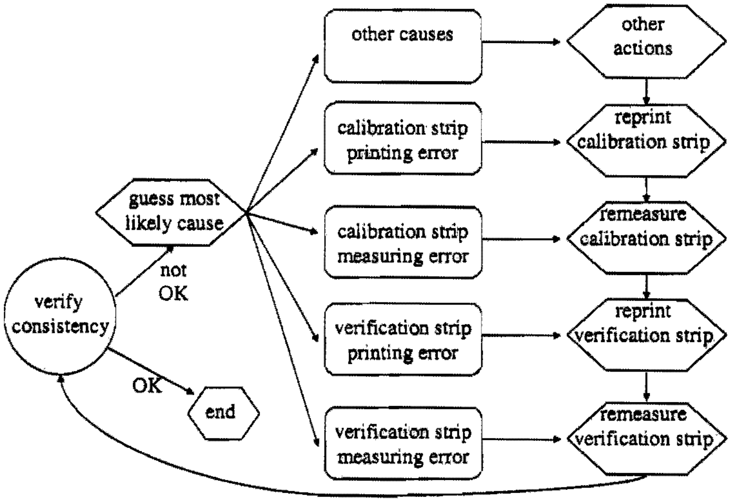

Figure 2: Partial diagram showing the hierarchy of problems and corresponding actions.

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 set out 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 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 and 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, perhaps that patch 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 paper type 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.

Proof Verification

In the proofer verification module, we manage the consistency of the proofer as such, independent of the process it will simulate. Therefore we investigated prints using calibration but without the use of colour management. This system of calibration and verification is what we call "quality managed printing", and was described in (Livens, 2002a).

For a complete control of the proofing, moving up to "quality managed proofing", the colour management part of the proofing solution has to be controlled as well. To achieve this, 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. Only now, we can rely on standards such as (ISO 12647, 1996).

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 for the final print. However now it is simulated of the proofer, meaning that it is run through colour management and outputted using a calibrated inkjet proofer. Given a consistent proofer, this test reveals the consistency of the colour management, thus of the combination of proofer and output profile. By combining this information with that of the print to reference verification, the inconsistent profile can be pinpointed.

Conclusion

Consistent colour 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 output system (the inkjet 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 linearisation, 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 paper types, a system was proposed that helps the user in making guided choices based on information about gamut and visual artefacts.

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

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