Streaks and Banding: Measuring Macro Uniformity in the Context of Optimization Processes for Inkjet Printing

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Abstract

Directional printing artifacts like streaks and banding are commonly encountered problems in digital printing systems. For example, inkjet systems may produce characteristic density variations due to inconsistencies between printheads or intra-printhead variations between nozzles. When these variations have a high spatial frequency they can be characterized as causing ‘streaking’ in the direction of print, where the variations have a low spatial frequency this can cause the appearance of ‘banding.’

Introduction

Other causes of directional streaking and banding effects may be due, for example, to variations in the speed of printhead or substrate velocities resulting in density variations across the direction of printing. The ‘wow’ and ‘flutter’ of the digital printing.

In the décor market there is a perceptual test sometimes referred to as a ‘porthole test’. In this test a human subject is presented with a print (e.g. wallpaper or floor covering) rotated behind a round window under controlled viewing conditions. If they can determine the direction in which the job was printed then the test is a ‘fail’. One aspect of the porthole test is that it allows for the perceptual response differences between different printed images. For example, the same press and conditions may be able to print one job containing a lot of graphical detail, but still fail on another job requiring flat tints.

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There are currently emerging standards designed to objectively characterize directional print variation. For example, the proposed ISO TS 18621-21 technical specification defines a measurement method for the evaluation of distortions in the macroscopic uniformity of printed areas that are oriented in the horizontal and/or vertical direction, like streaks and bands.

Such recognized standards could be useful for the development and maintenance of printing systems; as well as potentially allowing for the quantitative comparison of the general directional quality between different printing systems.

Having an objective ISO measurement of directional uniformity would therefore be a very useful step forward and something we at Global Graphics would like to encourage.

As a first step the current ISO TS 18621-21 proposal looks good and provides for a robust and simple metric that can be calculated using standard equipment.

However, in exploring the potential use of this standard we also note some potential limitations which may constrain the widest possible utility for a general directional measure in printing. For example, the frequency response of the proposed measurement technique may cause the response of the measure to miss higher frequency ‘streaking’ artifacts; this may be inevitable with the measurement devices available but this potential for spatial frequency bias needs to be clearly understood and accepted.

Another challenge in standardizing such a metric across different printing platforms is the difficulty in selecting an objective color tint to measure. The ‘goodness’ of the proposed ISO TS 18621-21 metric will depend on the color tint chosen for measurement; therefore making such measurements standard between systems with different color gamuts is a difficult and perhaps impossible task. Nonetheless we would like to propose a color tint selection strategy which at least *a priori* could have the potential to provide a selection of standardized color tints that could be used meaningfully with ISO TS 18621-21 across a range of different printers.

Many factors can contribute to directional printing bias in a complex system, environmental (e.g. dust, temperature and humidity); mechanical effects (e.g. vibration or printhead alignment) and electronic (e.g. waveforms or drive voltages). Uniquely processing software can be created which can automatically detect and compensate for optical density variations; based on scanning, image analysis and modulation of the print data.

A combination of physical and software strategies can yield improved directional quality delivering more cost effective and productive printing systems.

An example of software digital press density compensation is the PrintFlat™ system from Global Graphics, an OEM solution for delivering improved directional print quality. Such software allows intelligent press compensation to become a component in a wide range of industrial digital printing applications.

Background: the problem of streaks and banding in digital printing

Directional printing artefacts can notionally be separated between high frequency 'streaking' and low frequency 'banding'. Clearly the visual frequency at which the transition between streaks and bands occurs is subjective and may be influenced by many factors: notably the viewing distance. However from a printing-mechanical perspective we can generally differentiate between higher frequency components, which may have a per-pixel or per actuator element (e.g. printer nozzle) source, as opposed to pixel/actuator-element *collective* factors: for example variations between banks of nozzles in different inkjet printheads.

For the present discussion we can characterize *printing system* streaking artifacts as anything which has a pixel or actuator element dependent variation. Conversely printing system *banding* can be characterized as any directional variation which has a super-pixel or actuator collective bias.

For example a printing system which experiences randomly blocked nozzles (perhaps due to environmental contamination) can be described as suffering from 'printing system streaking', which may or may not correspond to perceptual streaking at any particular viewing distance.

Similarly 'printing system banding' can be characterized as any directional bias affecting a collective set of pixels/actuators. For example density variations between printheads perhaps due to manufacturing tolerances or ink supply variations will show up as bands coherently effecting the density of the nozzles array within each printhead.

In practice the distinction between perceptual and printing-system streaks/banding is important because the perceptual effect will be modulated by the viewing conditions and the image printed, whereas the underlying causes of printing-system bias can often be identified as having distinct causes in the underlying mechanics of the printing system.

The following discussion will generally be referring to printing-system streaking and banding. But it should be borne in mind that the ultimate perceptual effect of directional variation will be dependent on other non-printing factors such as viewing distance, lighting and image content.

The production costs of streaks and banding

Clearly, from an aesthetic perspective, printing artefacts like streaks and banding will detract from the quality of the printed image. However, it's worth considering how these problems impact on production costs as this can often help determine the best options for remedial action.

Production job restrictions

Often the impact of directional artifacts is felt in restrictions on the types of job that can be printed. It's not uncommon to encounter situations where only a minority of possible jobs can be printed digitally due to the high sensitivity of an application to directional artefacts. For example, in the décor market the combination of printing large areas and the relatively long viewing distances can make flat-tint jobs very sensitive to banding artefacts. Whereas some other types of décor images, e.g., wood grain may be relatively forgiving; particularly of high frequency streaking in the direction of the wood grain.

In general jobs containing large areas of flat tints, particularly in sensitive colors such as greens or purples, will be intolerant of any directional bias. A classic example of difficult large format images would be ones containing large amounts of blue sky, unfortunately a common motif in many situations.

The economic costs of this kind of job restriction can be felt both as underutilization of digital printing capacity, and the high costs of running short-run print runs on analogue presses. And a continuing requirement to maintain multiple types of printing system may be a significant cost and organizational challenge.

An objective measure of the production cost of streaks and banding in a digital printing system is the percentage of potential jobs that have to either be turned away or printed on alternate systems.

Price discounted output

Another situation that can occur is where output generated with significant directional artefacts is sold at a discount. This tends to apply to industries where the underlying substrate itself has some intrinsic value, for example in ceramic tile production and flooring generally. In this case we can directly measure the cost of directional artefacts in the discount provided, which may be as much as 50% of the factory gate price, providing a big economic incentive to fix problems at source.

The costs of remediation

Building and maintaining digital printing systems with an inherent tendency to directional artefacts can be expensive. And in the context of inkjet systems, this may involve:

- Additional purging and cleaning cycles.
    - wasted ink and interrupted production

- Printhead voltage trimming for density adjustment
    - interrupts production and can reduce the lifetime and operational stability of printheads

- Expensive environmental and/or substrate conditioning
    - Air filtering and temperature/humidity control

An indirect cost: broken color workflow

One of the surprising problems with directional bias is the negative effect it can have on generating accurate color profiles. The normal color workflow involves printing a range of color patches that are measured with a spectrophotometer. This workflow relies on each patch being representative of the printer as a whole, but if there is any positional or directional bias in the printed patches, e.g. from bands or streaks, then the color density readings will be inconsistent across the page and the color profile generated will be wrong. Not only can this produce inaccurate color profiles but the underlying color model may not be consistent, potentially leading to unstable and contradictory color transforms.

In practice the indirect problem of broken color profiles can be one of the most significant effects of directional printer variation. After all it is possible to select jobs that are less sensitive to direction variations, but every job will need to have accurate, and above all consistent, color reproduction.

Causes of high frequency printing system streaking

High frequency output-pixel or nozzle-level directional variations can have a number of different causes.

Missing nozzles

A common problem with digital inkjet systems in that of a blocked or defective nozzle. Clearly if a nozzle is missing, then other things being equal, the ink density that this nozzle should have provided will be missing from the print; leading to a light-density streak at that nozzle position.

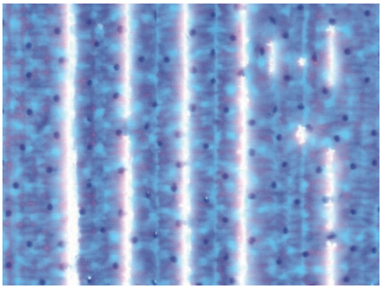
In terms of identifying causes and potential remedies it is important to characterize different types of nozzle defect. For example, a nozzle may be defective due to:

- An intermittent contamination of the nozzle aperture:
    - Environmental dust particles?
    - Bubbles forming in the ink at the actuator?
    - Flocculation of ink pigments?
    - Misting of ink onto the face plate?

- Or it may be a permanent actuator defect:
    - Manufacturing yield?
    - Printhead aging?

A nozzle defect can also be characterized in terms of whether the drops are entirely missing or simply deflected. In both cases a low-density streak will be visible but the effect of a deflected nozzle on the average density typically depends on the type of substrate. Printing onto a fully-wetting or absorbent substrate should provide the correct average area density from a deflected nozzle as the pigment is landing and spreading in roughly the correct place. However on poorly wetting or UV-pinned ink systems a deflected nozzle can also produce a reduction in average area density due to self-shadowing effects, thereby mimicking the effect of a missing nozzle.

Similar 'tram-line' down-web streaking can also be seen if overlapping printheads are not correctly aligned on poorly wetting or UV-pinned ink systems. This is because the 'comb' pattern at the edge of one array may sit on-top of rather than interstitially with another the comb pattern from the neighboring array.



'Tram-line' effects due to incorrect stitching alignment of UV-pinned ink system.

Timing jitter

High frequency streaking artefacts can sometimes be recognized in the actuator array direction (i.e. across-web on web based digital print-bar systems). This can typically be due to timing jitter in the actuator electronics. Encoder systems designed to compensate for substrate transport speed variation can sometimes introduce high frequency electronic noise into the actuator-firing timing path. Normally this type of issue should be fixable in the encoder electronics.

Two dimensional orthogonal (crisscross) streaking

Different types of high frequency mechanical vibration may sometimes cause streaking to occur in both orthogonal directions as the actuator array is physically displaced relative to the underlying substrate.

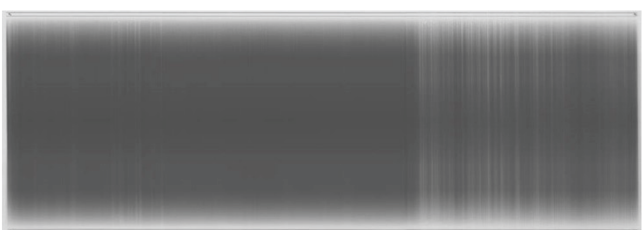
If 2D streaking issues are seen only in composite colors but not in the pure process colors, then this is likely due to screening problems, i.e. interference or moiré between the screens used in separate color channels. This can be caused by for example re-using one screen cache in multiple color separations and is normally a software fixable problem.

Causes of low-frequency printing system banding

Collective density variations are usually linked to mechanical features of a printer. For example one printhead may vary in average density from another due to manufacturing tolerances. Alternatively, one printhead location may vary consistently from another location due to deviations in ink-system circulation pressure or flow-rate.

Down web banding

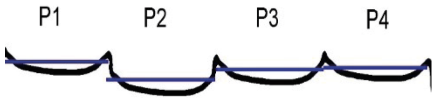
The following image shows the typical effect that can be seen when one printhead in a system is out of specification. A broad print band corresponding to the defective printhead shows both higher variability and lower average density than neighboring printheads.



A histogram of the average nozzle densities shows how the printed output corresponds to the individual nozzle array output.

Another common cause of down-web banding is intra-printhead density variations. Many printhead types can exhibit an inherent bias between the central and edge nozzles which can for example be due to pressure or flow differences from the pattern of internal ink recirculation. These types of issue can produce the classic printhead 'smile' density variation, characterized by bands of greater or lower density around the edges of printheads.

The following diagram illustrates the case where a four printhead array varies both in average inter-printhead density (blue lines) but also a consistent intra-printhead 'smile' density variation.



Across web banding

Low frequency banding in the across-web direction is most commonly caused by variations in the transport speed, like the 'wow' and 'flutter' experienced playing a vinyl record on an unstable turntable. Solutions include more stable transport and/or transport encoders to drive the printer actuators at a variable rate to match the transport speed. This type of across-web variation can also be due to low-frequency vibrations, for example heavy lorries passing by or even earthquakes. Mechanically isolation large system from all types of low frequency vibrations can be challenging.

Measuring Directional Printing Artefacts

Depending on the objective, a number of different techniques may be used to measure the directional quality of a print or printing press.

The 'porthole' test

In the décor printing industry a test sometimes known as the 'porthole' test involves a human subject viewing a circular window at a constant distance and lighting conditions. Behind the window the print is mounted on a rotating frame. If the viewer can easily tell the direction of the printing as the image is rotated, i.e. from directional streaks or banding due to the printing process then the image is considered a 'fail'.

reference print

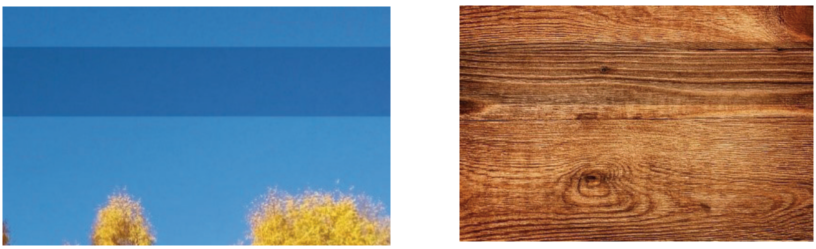
In the above exaggerated example, banding variation is clearly visible due to density differences in the Cyan channel.

The porthole test is useful in determining whether printing is consistent with the quality required for that job. Clearly some images are much more challenging to print than others; in the above example, a flat green tint, would be a difficult to reproduce well on a printing press that had directional problems.

Press or Print?

The following images illustrate the difference between underlying press characteristics and job characteristics.

without banding



Single band in Cyan channel only

The same underlying printing bias in the Cyan channel of a printing device is much more noticeable when reproducing the sky image compared to a wood grain.

Emerging measurement methods

Currently in progress is an ISO Technical Specification as part of the ISO Graphics Technology: *Image quality evaluation methods for printed matter*. In this work part 21 deals with measuring directional printing bias:

> ISO/NP TS 18621-21: *Measurement of 1D distortions of macroscopic uniformity utilizing scanning spectrophotometer*.

The working draft for ISO/NP TS 18621-21 proposes measuring a grid of points on an A4 sheet printed in a constant color. The sum of the normalized differences in vertical and horizontal directions (ΔE_{total}) is then used in a formula which aims to reproduce a roughly linear psychophysical response.

Frequency response

One of the challenges for the ISO/NP TS 18621-21 proposal is that the sensitivity to the frequency of spatial variation will be dependent on the sampling interval. In the proposed scheme a sampling interval of 6mm is suggested, while this may accurately capture lower frequency banding variations, it could also underestimate higher frequency streaking variations.

This can be a particular problem because certain types of directional artifacts are linked to specific spatial frequencies, i.e. nozzles to the nozzle pitch and printheads to the printhead pitch, etc. Furthermore the visual frequency response is dependent on the viewing distance. So for example, a metric based on a fixed sampling frequency may not be equally useful for label printing compared with large-format poster printing intended to be viewed from a greater distance.

Where streakiness is random and un-correlated with lower frequency banding changes in high frequency streakiness can be expected to show up statistically as variations at lower frequencies (i.e. a white noise distribution). However, there are printing compensation systems available (such as PrintFlat™) which can correct for directional variations so that high and low frequency variations may no longer correlated in a gaussian way. In such a case the proposed metric could be blind to improvements in high frequency streakiness variation above the band-pass of the sampling system.

A possible recommendation might involve extending the proposed method to use scanned data, which would allow capturing of higher frequency streaking variations. For example, as suggested in ISO/DTS 18621-31.3 *Evaluation of the perceived resolution of printing systems with the contrast – resolution chart*.

Color selection

Another challenge with the ISO/NP TS 18621-21 proposal is what constant color to use as the measurement target. Different presses will have different color gamuts and more saturated colors have more optical density to vary.

As the proposal does not specify the printed color to use, objective comparisons between systems based on this metric would be difficult. For example, one can expect an apparently better metric to result from printing a 5% tint compared to a 70% tint of the same ink. Therefore, an objective method for selecting the target color tints could be helpful.

A possible way to determine a meaningful inter-press target color might be to choose the mid-point optical density for each press process color. These values could then be compared between presses to get an indication of the general 'directional bias factor for a given press (and/or process color channel)'.

Fixing directional printing artefacts

Ultimately the directional uniformity of a complex printing system will be the sum of many different factors. One can divide ways to tackle such problems into environmental, mechanical, fluidic, electronic and finally software.

Digital printing is a directional process, unlike the original Caxton press where images were stamped out, digital presses always print in a linear fashion. Clearly therefore such a process has an inherent tendency to directional variation, so all the physical components must work in concert to provide a uniform and stable a printing process. Uniquely, software can also be used measure and then intelligently compensate for density variations in a feedback loop. Such adaptive compensation can best be thought of as a 'final polish', just as in carpentry the first cut must be straight, but only polishing can produce a surface which it truly flat.

Mechanical fixes

For example, if problems with intermittently dropped nozzles has a root cause in environmental variability then controlling for dust, temperature and humidity can produce a marked improvement

Mechanical fixes may can include designing systems to avoid the need for interstitial nozzle alignment, either at stitch boundaries or from multiple print bars.

Fluidic system fixes

However if interstitial nozzle alignment is still necessary then careful selection of substrate types and ink fluidic properties can reduce the tendency for 'tramline' imperfections if there are slight deviations to the nozzle alignment. Generally increasing the relative wetting or absorbency of the substrate/ink system will tend to be less susceptible to nozzle alignment issues.

Electronic fixes

For high frequency streaking problems electronic fixes may include tuning of waveforms for better drop formation (e.g. less tendency to block, increased ability to restart and/or producing fewer satellite drops producing less faceplate misting).

For lower frequency banding problems electronic fixes often include driver voltage trimming of the voltage banks within a printhead. This can be effective but is time consuming and may undermine the stability and lifetime of the printhead if pushed beyond recommended actuator tolerances.

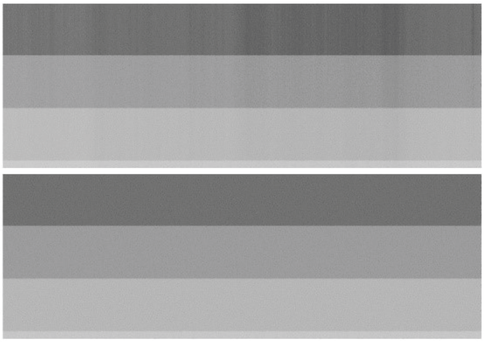
Thermal modulation is sometimes used as an adjunct to voltage trimming, effectively adjusting the ink viscosity to adjust for low frequency variations in printed optical density. As with voltage trimming this can be a labor-intensive process to perform successfully and can lead to inconsistencies between the density gain behavior of different drop sizes.

Software fixes

Uniquely software fixes can sense and adapt to density variations (of both high and low spatial frequency) caused by the underlying composite physical system.

When one considers the physical complexity of high throughput digital printing systems and their inherent directionality, it should not be surprising that, at least for sensitive applications and particularly for single pass systems, such compensation may ultimately be the only effective way to achieve a reliable 'flat' optical density profile.

The following image shows before and after results from the application of Global Graphics Software PrintFlat™ technology.



The basic components of software press compensation systems are:

1. Some way of capturing the press variation, normally involving optical scanning.

2. Algorithms to interpret the scanned results and adjust for measurement bias (e.g. scanner bias) to produce unbiased density compensation data.

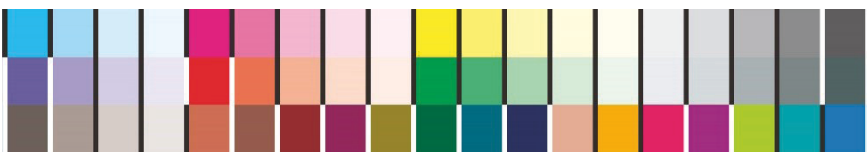
3. Algorithms to apply the press compensation data to the image to produce a press-compensated rendering.

The key challenge with software systems is to avoid system biases; which can as easily inject directional artifacts into a system as remove them. Due to the inherent challenges, relatively few software press density compensation systems have been successfully developed, and most of these are closed systems designed for specific digital presses.

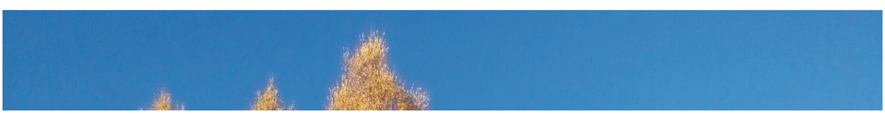
With PrintFlat™ technology Global Graphics Software has developed a uniquely general purpose software press density compensation solution. Designed to allow digital press OEMs to integrate a highly effective software press compensation component into a range of different print devices.

Potential benefits

Potential benefits of software press density compensation include that color patches can be printed more consistently across the page, so color calibration becomes more accurate and reliable:



The sky can look smooth and streak free:



And flat tints can be printed flat:

The results seen with PrintFlat™ have often been quite remarkable: surpassing quality that takes days to achieve using mechanical, fluidic and electronic press adjustments.

For an industry example of the PrintFlat technology in use please see the YouTube video: "*ScreenPro™ with PrintFlat™ removes banding on large format posters for Ellerhold AG.*"

Presses will always need careful physical set-up and maintenance, but in many cases it is only software press compensation that can provide the intelligent optical density analysis and feedback required to achieve a visually flat density response.

It seems likely that software press density compensation will become a common component in digital-print engineering solutions. This should allow digital presses to routinely meet and surpass the directional fidelity of traditional analogue presses for most industrial printing applications.

References

1. ISO/NP TS 18621-21 "Measurement of 1D distortions of macroscopic uniformity utilizing scanning spectrophotometer", ISO Technical Committee: ISO/130, Status: *Under development*, 2019

2. ISO/DTS 18621-31 "Image quality evaluation methods for printed matter -- Part 31: Evaluation of the perceived resolution of printing systems with the contrast –resolution chart", ISO Technical Committee: ISO/130, Status: *Under development*, 2019

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