Optimizing Stability: Software Density Compensation for Improved Printing Stability

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Abstract

Software density compensation for increasing uniformity is gaining acceptance as a solution to eliminate banding artifacts in Inkjet digital printing. Compared with tuning physical parameters software compensation can be more efficient and produce a more uniform result. This paper highlights an additional significant benefit: using software density compensation can free up physical parameters to be optimized for stability: i.e. stable jetting, fewer dropped nozzles and lower PrintHead variability over time. We demonstrate that different printheads have greater intra-head stability at different printing densities. Paradoxically therefore by increasing inter-head density variations we can increase overall system stability. In conjunction with PrintFlatTM density compensation this insight can create a system which still has no banding but may be significantly more stable.

Introduction

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.

These directional variations have historically been tackled by careful tuning of physical parameters such as drive voltages and/or thermal profiles to produce a fairly uniform density across the press. However, limitations with this approach include the granularity of control: different drop sizes, for example, may not respond the same to changing physical parameters, so density variations may not vary consistently between light and dark areas. Also software compensation may be easier to automate, is often faster than adjusting physical parameters and

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Global Graphics Software Ltd, Cambridge, UK; InterTech Award

require less expert technicians to perform: potentially yielding important gains in workflow efficiency.

To improve the quality and efficiency of directional density compensation we developed PrintFlat™. This system analyses test prints and automatically compensates density at high resolution during the digital screening process. In 2019 this software was the recipient of a PIA InterTech™ Technology Award for innovation andPrintFlat™ is now being adopted across a wide range of inkjet printing applications in graphics, packaging, décor, textile and billboard printing.

This paper reports on a novel way of using software density compensation (such as PrintFlat™) to significantly enhance not just quality but also overall printing system stability.

Background: the problem of stability in inkjet digital printing

The fundamental challenge for inkjet is the physics of the micron-scale domain in which picoliter drops operate; which can be referred to as the *mesoscopic* physical domain. At this scale nanoscale molecular interactions, such as dynamic viscosity and surface tension, become increasingly important. However macro scale forces of bulk mass and thermal inertia are still strong. Therefore picoliter scale drops are subject to a complex dynamic equilibrium between many strong forces with different scaling parameters. So, for example, as drops get smaller the relative strength of surface tension increases greatly while the effects of mass inertia diminish, significantly altering the way in which drops evolve over time. Just as a mouse does not behave like an elephant, the *behavior* of drops changes, e.g. modes of coalescence and transport change greatly with physical and chemical parameters. The effects of heat, chemistry, humidity, air flow, electric fields, particulates, bubbles are all felt strongly at the mesoscopic scale in which inkjet operates.

Bringing these physical parameters into perfect dynamic equilibrium to achieve consistent printing density on a printed page is not easy. Engineers working at large scales on machinery or on small scales like electronics may not fully appreciate the challenges of working with effects from both bulk and molecular scale forces at the same time. It is these inherent scale-dependent challenges that underly the engineering requirement for software density compensation for micron-scale digital printing systems.

From this discussion we can appreciate that printing components, for example printheads, often seem to exhibit *personalities*. Like trying to balance a teapot on a pin, the slightest variability in physical conditions may tip the dynamic balances that underly inkjet in one direction or another; producing subtle shifts in density that may not show up until the ink is dry on the substrate.

Software density compensation is a good solution to the density instability engineering challenge. In many ways this is analogous to the use of fly-by-wire in military jets: fly-by-wire allows the aerodynamics of an aircraft to be dynamically unstable to provide enhanced performance. Like jet-planes, high performance inkjet will always push the engineering envelope of fluid dynamic instability.

Tuning for stability not density

A nice thing about using software density compensation is that it frees up whatever physical parameters were used previously for density compensation. These parameters, e.g. driver voltages, can now be deployed to other tasks like increasing printing stability or printhead lifetime.

One approach is to set voltages to manufacturer recommended driver voltages. This ought to produce optimal performance, however in reality printheads often vary *in situ*, either intrinsically or because of minute differences in their immediate environment (ink-pressures, mechanical vibration, temperature, throw-distance, down-web position, aerodynamic effects, etc.).

This suggests a new opportunity. Rather than tune for density we wondered if it might be possible to detect and tune printheads for ‘sweet spots’ in their jetting stability?

For example, it may be that intra-head variability or the frequency of dropped nozzles might vary between printheads at different driver voltages irrespective of density. To explore this possibility, we set up a test rig with two, notionally identical, printheads and measured the density variance from each printhead at different driver voltages.

Experimental Design

For this initial work we had very limited time so chose a simple experimental design.

Test rig

A small inkjet development rig was set up with good control of environmental parameters, containing two side-by-side high quality industrial printheads (unfortunately for commercial reasons we cannot identify the manufacturer). These are conventional industrial inkjet printheads in widespread use in a range of industrial inkjet applications.

Both printheads were driven from the same ink supply system using manufacturer recommended inks. We had independent fine control over each printhead driver voltage via the Meteor Inkjet driver card circuitry.

The rig was set up with one new printhead and one which was relatively old (> 6 months). The old printhead tended to exhibit more variance generally than the newer head as is typical.

Test pattern

We chose a test print pattern to minimize any secondary effects from substrate wetting or curing (i.e. each drop was placed in a separate 5x5 pixel space). The pattern also ensured that each nozzle of the printhead was exercised uniformly.

Voltage range

We decided to test an arbitrary 10-step driver voltage in a range from 17V to 26V, set digitally from the driver card control software.

Test procedure

We printed the chosen test pattern using both printheads simultaneously onto sheets of A4 coated stock paper.

Two sheets were printed for each voltage from 17V to 26V (20 prints).

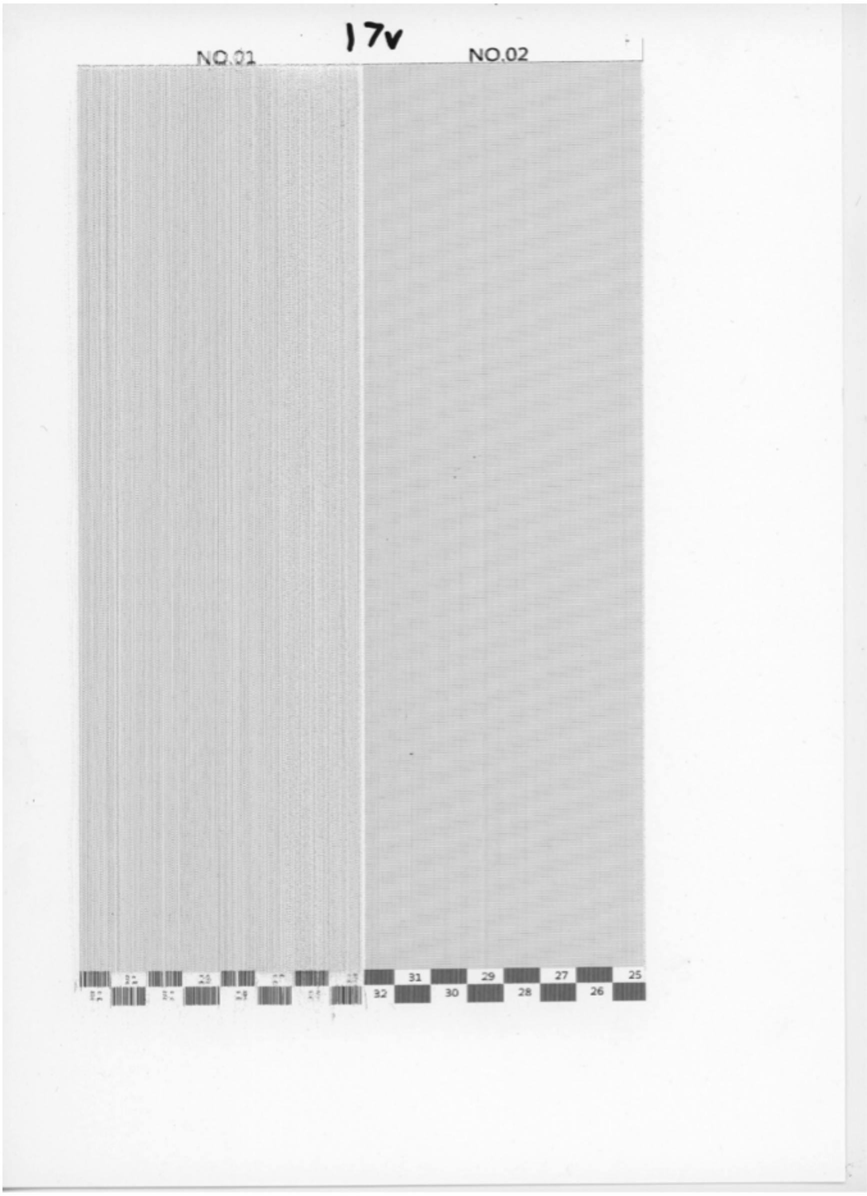
Each print was scanned on an Epson Perfection V850 Pro flatbed scanner which has good optical density sensitivity.

Data processing

Using an automatic software procedure, we captured an approximately 10cm2 patch from each printhead taken from the center of the pattern area.

We then measured the relative density and density variance of each patch.

Results



Sample print at 17V, PH1 on the left, PH2 on the right. The older printheads on the left shows more directional variance than the newer printhead on the right.

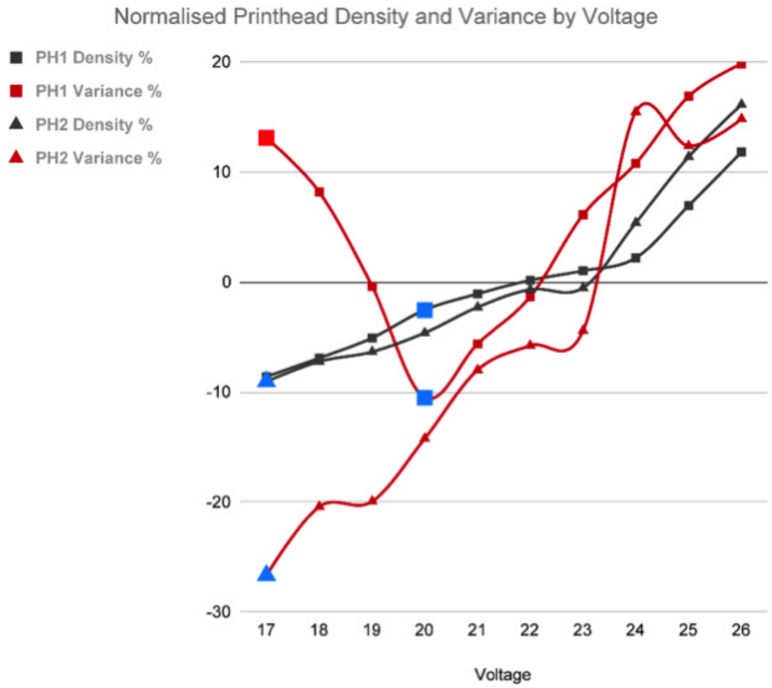
The following data was collected from the experiment. The Relative Density is given as +/- percentage relative to the average density of both heads. The Relative Variance is the +/- percentage relative to the average variance of both heads. Presenting the data in this format allows the data to be mapped meaningfully onto the same range. Each result sown was averaged from two separate print measurements. Printhead 1 and Printhead 2 printed simultaneously onto the same substrate for each print.

Printhead 1	Drive Voltage	Relative Density	Relative Variance
	17.0	-8.6%	13.1%
	18.0	-6.9%	8.2%
	19.0	-5.1%	-0.4%
	20.0	-2.5%	-10.5%
	21.0	-1.1%	-5.6%
	22.0	0.2%	-1.3%
	23.0	1.0%	6.1%
	24.0	2.2%	10.8%
	25.0	6.9%	16.9%
	26.0	11.8%	19.8%

Printhead 2	Drive Voltage	Relative Density	Relative Variance
	17.0	-9.0%	-26.7%
	18.0	-7.2%	-20.4%
	19.0	-6.3%	-19.9%
	20.0	-4.6%	-14.2%
	21.0	-2.3%	-8.0%
	22.0	-0.7%	-5.8%
	23.0	-0.5%	-4.4%
	24.0	5.4%	15.4%
	25.0	11.4%	12.4%
	26.0	16.1%	14.8%

In the data we can clearly see that the newer Printhead 2 exhibits substantially lower minimum variance to -26.7% @17V (compared to the average of all measurements).

Analysis



The above diagram shows the relationship between print density and variance for the two printheads over the experimental driver voltage range.

Points to note include:

- the generally lower variance of the newer Printhead 2
- the monotonically increasing density of both printheads with driver voltage
- The clear variance minima characteristic of the older printhead (PH1)
- The surprisingly steep relationship between drive voltage and variance for the new printhead (PH2).

Various voltage driver policies could potentially be enacted:

- Set the voltages to the same recommended default values, i.e. 22V.
    - In this example this policy would work quite well as far as density is concerned with the new printhead (PH2) coming out just a few % lower density than the older one (PH1). However, this voltage is clearly sub-optimal from a density variance point of view for both printheads.
- Set the new printhead to mimic the density of the older printhead.
    - This policy would be typical if a new printhead is installed in an existing digital press. In this case if PH1 was already at 22.0V PH1 would intersect this density value at about 23.2V. However, at this voltage PH2 is starting to climb dramatically in intra-head density variance, indicating that printhead stability would be significantly worse.
- Set each printhead to its intra-printhead variance minimizing value (blue square and blue triangle on red curves).
    - These voltages have the prospect of much lower intra-head variance and therefore likely printhead stability. These voltages (PH1 20.0V, PH2 17.0V) would generate significantly different densities from the two printheads (-8% and -3% compared to average density, an approximately 5% difference in absolute density). This is still well within the range where software compensation, e.g. PrintFlatTM, can eliminate banding. And as the underlying intra-printhead variances are much lower the net quality and stability is likely to be significantly improved.

Clearly the experiment demonstrates that the opportunity exists for these printheads to reduce the baseline intra-head variance by setting variance-minimizing voltages. In this experiment for both PH1 and PH2 this reduction in variance would be significant (10-20% of total variance). However, setting these voltages would yield an average density difference between the printheads of about 5% which without software mitigation would result in printhead density bands in the output.

Discussion

The general significance of these results still needs to be replicated and the wider scope determined. Different printheads and press configurations will determine the extent and effectiveness of this technique for improving print stability. And different vectors of stability can be considered, e.g. frequency of dropped nozzles, average density change over time, printhead lifetime, etc.

The potential also exists to automate this process. Once could envisage a system which prints and scans test images, perhaps at different times, to determine automatically optimal process parameters (e.g. printhead trim voltages) for enhanced press stability. Used in conjunction with software density compensation such a system could work to automatically improve both press stability and print quality.

We would welcome collaborations to explore these issues and to develop the potential of this technique for improved press stability.

Conclusion

The results are tantalizing. Even in this quick investigation clearly the opportunity exists to improve printing stability by tuning physical parameters for stability while using software compensation to deal with resulting increase in baseline density variation.

It was a surprise that, at least in this experiment, the scope for stability improvements by this technique appears to be quite significant. The length of project did not allow for follow up investigations. However, anecdotally we believe that lower intra-head variance will be correlated with printhead stability over time. It is known that there is often a correspondence between driver voltage and missing and deflected nozzles. This needs more careful investigation but promises to usefully address one of the most challenging issues in digital printing quality and stability.

Paradoxically by loosening control of printhead average density we may achieve greater printer stability over time.

For an industry example of the PrintFlat technology in use see the YouTube video, see:
"ScreenPro™ with PrintFlat™ removes banding on large format posters for Ellerhold AG" https://www.youtube.com/watch?v=7gtQll8BQqg

For a general introduction to PrintFlatTM technology, see:
https://www.youtube.com/watch?v=IyJfgUghX3E

References

US patent application ref:… TBC

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