Evaluation of Crosstalk Effects in Inkjet Printing with Xaar 1001

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Abstract

Measurements of crosstalk-induced dot placement errors were conducted with the Xaar1001 printhead printing in 3-phase mode using multiple different print patterns containing active pixels from nine neighboring channels on both sides of the monitored channel and including pixels from four earlier print cycles. The test data attributed a 'crosstalk weight factor' to each pixel proportional to its effect on the drop velocity of the monitored channel. The largest crosstalk effect was exerted by the nearest phase neighbor channels, and they reduced the drop velocity from the monitored channel. The 'crosstalk weight factors' of the other pixels was typically one order of magnitude smaller, and they were partially positive or negative, i.e. that they increase or decreased the drop velocity, respectively. The test results further proved that the total crosstalk effect of large print pattern as calculated by a linear superposition of the individual 'crosstalk weight factors' of the active pixels was within 4% of the measured data . The evaluation of crosstalk was further supported by measurements of the meniscus motion within the nozzle in real time. This provided the possibility to measure the pressure variations within printing and non-printing channels, and thus enable to monitor the 'pure' effect of crosstalk from neighboring channels.

Introduction

Drop formation in DOD-printheads results from pressure waves within the ink channels. Drop velocity and volume change when neighboring channels are active as well, and the effect of such 'crosstalk' is visible e.g. as dot placement error. The ability to measure crosstalk effects quantitatively are the basis for the development of image manipulation and waveform optimization to compensate for crosstalk related dot placement errors. The present work describes two approaches to analyze crosstalk in a Xaar1001 printhead. The first method uses precise measurement of dot placement errors from print outs and calculation of the quantitative effect of each individual pixel of a print pattern. The second method measures the motion of the meniscus in a nozzle in real time. While this method works at very low driving voltages below the threshold for drop ejection and was not used for quantitative predictions of drop velocity and dot placement it proved very useful in providing online data on relative pressure variations in the channel. It is thus useful for evaluating prototype actuators or fine tuning of driving waveforms.

Crosstalk Analysis from Printed Pattern

Cross-talk was measured in two different approaches. Quantitative data of drop velocity changes and dot placement errors was obtained by print tests. The tests were carried out on a drum printer with drum diameter of 100 mm and with a Renishaw encoder RESM20. The ink of choice was Magenta SunJet Crystal UFX and the Xaar1001 printhead was driven with a basic waveform for this particular ink. Throughout the reported tests the printhead was run at a its nominal maximum firing frequency of 6 kHz, the nominal drop velocity of 6 m/s, and at a grey level of 3 dpd. Print distance between the printhead and the paper surface was kept at 0.7 mm. A suitable coated paper (Epson glossy photo paper) was selected to produce well defined round dots that could be detected with high precision with a Mitutoyo Quick Vision ELF tool.

In a first sequence of test runs the optimum substrate speed was evaluated that would give the highest measurement resolution of the crosstalk induced dot placement errors. The crosstalk effect on print quality can be quantified in different fashion, either by presenting the absolute dot placement error Δs or by the relative drop velocity change $\Delta v_D/v_D$. Since the absolute dot placement error depends on the print distance it is more favorable to describe the crosstalk effect as the relative drop velocity change, which can be calculated from the dot placement error as in formula (1).

$$\Delta s = \frac{h\ v_s\ (\Delta v_D / v_D)}{v_D\ [(\Delta v_D / v_D) - 1]} \tag{1}$$

When plotting the absolute dot placement error versus the relative drop velocity change for different substrate speeds v_S it is obvious from figure 1 that for a given accuracy in the measurement of dot placement the higher substrate speeds result in an improved resolution in the crosstalk effected relative drop velocity change. At too high substrate speeds, however, it was observed that dots did not show round shapes and that wind effects between the substrate and the printhead started to affect the measurement accuracy and the placement of drops, respectively. A substrate speed of 1.68 m/s, four times the standard substrate speeds, was therefore selected for the test runs. Analysis of the printouts indicated a measurement repeatability of dot placement of 1-sigma of +/- 2µm, which together with a required signal-to-noise of 3:1 resulted in a measurement resolution of +/- 6 µm for the dot placement error. By way of formula 1 and depicted by figure 1 this enabled a resolution of the relative drop velocity change of 2.5%.

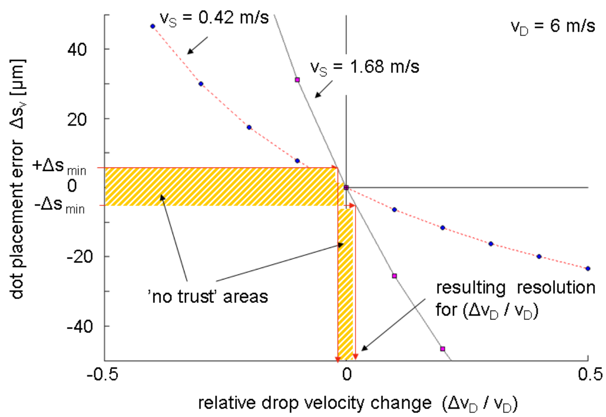

Figure 1: Relationship between the precision of dot placement measurements and the resulting resolution of the relative drop velocity changes.

The print patterns for the measurement of the effect of crosstalk on dot placement were arranged as depicted in figure 2. A sequence of single dots was printed from the ink channel under investigation with intervals of typically 50 pixels. These dots served as reference dots and allowed to measure precisely the nominal distance between the pixels on the substrate without any crosstalk active. After several of these single dots a specific print pattern was printed, which comprised both the dot from the channel under investigation as well as the specific print pattern to be evaluated. These various print patterns investigated included either single dots from channels printed in the same print cycle as well as dots printed in previous print cycles. The crosstalk effect of the specific print patterns on the ink channel under investigation caused dot placement errors, which could be measured as the difference between the actual position of the dot from the channel under investigation and its nominal position as calculated from the reference dots. This type of print pattern was repeated across the printhead with approx. 50 channels interval, so that 9 identical patterns were printed across the 500 channels of a single actuator row of the Xaar1001 printhead.

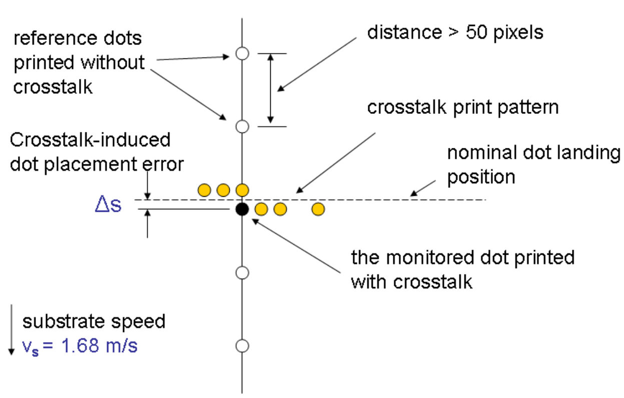

***Figure 2:** Reference dots (open dots) were printed with intervals of 50 pixels to allow calculating the nominal dot position of the monitored channel. The dot placement error due to the specific print pattern (grey dots) was measured as distance Δs between the actual position of the monitored dot (black dot) and its nominal position.*

For the present investigation of the crosstalk effect a total of 59 different print patterns were designed using different combinations of a total of 33 different active pixels. Eight of these print patterns are shown in figure 3 comprising printing of individual and multiple dots within a print cycle in three phase mode with the corresponding crosstalk related dot placement errors on the right side of figure 3. Two prints per print pattern and per each of the nine monitored channels across the Xaar1001 printhead were performed to allow for statistical analysis of the measurement data. Figure 3 demonstrates that the crosstalk effect of the two direct neighboring channels is minor as compared to the phase neighbors, and further that the crosstalk effect is linearly cumulative.

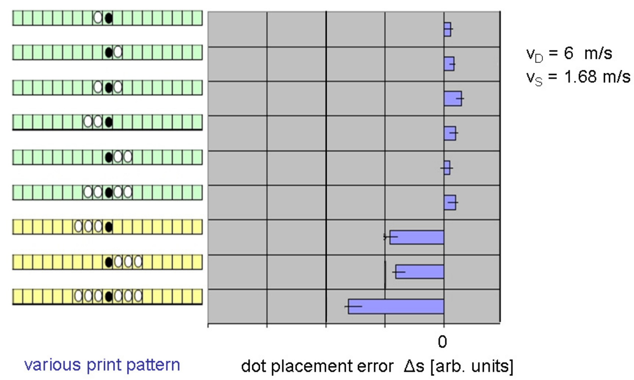

Figure 3: Several examples of test pattern on the left side. The black dot represents the monitored pixel while the open dots indicate pixels from neighboring channels printed in the same cycle.

Since the drop formation in Xaar-type printheads is based on acoustics within the channel it was assumed that the crosstalk effects of the individual active channels can be linearly super-positioned to yield the total crosstalk effect of each specific print pattern. With this assumption the crosstalk effect of each individual channel could be calculated from the set of dot placement errors of the different print pattern as

$$\Delta s_{calc} = \sum_{i=1}^{n} p_i \, cw_i \tag{2}$$

where p represents the individual pixel (1 of active, 0 if non-active), and cw defines a 'crosstalk weight factor' representing the strength of the crosstalk effect of this particular pixel on the monitored channel, and i numbering all pixels of the print pattern under consideration. The reported test run with 59 different print patterns provided 59 linear independent equations to calculate the 33 'crosstalk weight factors'. Solving this set of equations provided the results depicted in figure 4. Here only the pixels on one side of the monitored channels are shown since both sides were symmetric in performance. The accuracy of this procedure was tested to deliver calculated crosstalk related dot placement errors within 4% of the measured data. As mentioned above the crosstalk effect on dot placement was highest for the next phase neighbors, and as shown in figure 4 these phase neighbors affected a considerable reduction in drop velocity for the monitored channel. Some pixels that where printed in earlier cycles had positive ‘crosstalk weight factors’ and therefore resulted in slightly increased drop velocity.

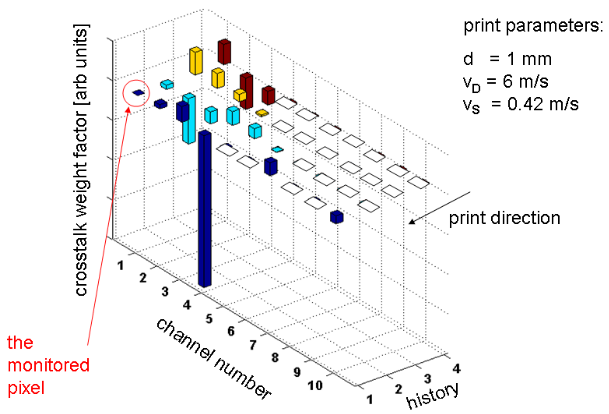

Figure 4: Calculated ‘crosstalk weight factors’ for 18 selected pixels from neighboring channels and within the same print cycle as well as three cycles prior to the monitored pixel.

By way of identifying those crosstalk weight factors it is possible to calculate the effect of any arbitrary print pattern according to formula 2. Such quantitative knowledge of crosstalk effects can be used for software/waveform based methods to compensate crosstalk related dot placement errors either off-line or even on-line.

Crosstalk Analysis by Meniscus Motion

Another method to investigate crosstalk effects within a printhead monitors the motion of the ink meniscus as an indicator of pressure variations within the nozzle. At very low driving voltage to the printhead, i.e. way below the threshold for drop ejection, the displacement of the meniscus surface can be considered linearly proportional to the pressure in the nozzle. Working well below the threshold for ejection it is therefore possible to monitor the pressure in a nozzle both for non-active as well as for active channels, since the latter is not ‘obscured’ by a drop formation process. Figure 5a to 5c show examples for the temporal pressure profiles for three different cases, (a) an active channel printing an individual grayscale pixel without activating neighboring channels, (b) the same active channel printing the grayscale pixel while printing a certain grayscale print pattern with neighboring channels, and (c) the monitored channel being non-active while printing the same print pattern of the neighboring channels as in case (b). The three figures can be evaluated to indeed show that the acoustic signals are additive, and that the difference of the signals in figures 5a and 5b indeed equal the curve in figure 5c. This proves that case (c) indeed provides the pure crosstalk effect of the neighboring channels on the monitored channel. The specific print pattern contained active phase neighbor channels and it is clearly visible that crosstalk results in a reduction of the pressure in the nozzle. This is in line with the observations from the print tests, which show a negative ‘crosstalk weight factor’ for the phase neighbor channels printing in the same cycle. It must be assumed that the requirement for sub-threshold operation does not allow predictions of e.g. drop velocity. However, the meniscus measurement provides a highly versatile method for online investigation of pressure effects in the channel, which is most useful for tests of prototype actuators or for waveform optimization.

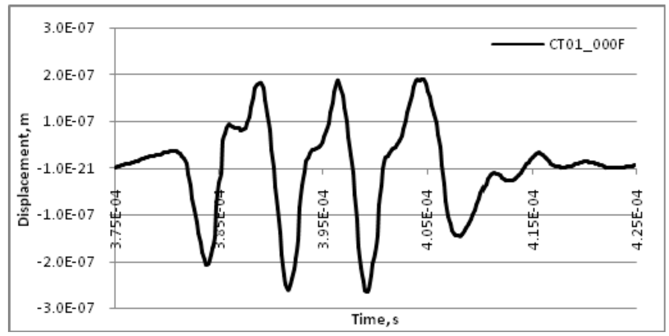

Figure 5 (a): Pressure at the nozzle for printing an isolated grayscale pixel only

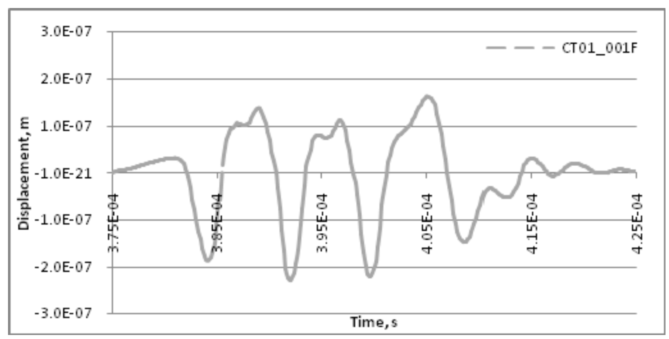

Figure 5 (b): Pressure at the nozzle when printing a grayscale pixel with the monitored channel and printing a specific pattern with the neighboring channels.

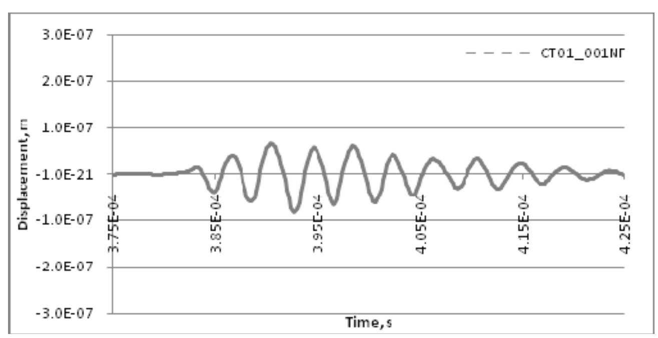

Figure 5(c): Pressure at the nozzle of the non-active channel with the neighboring channels printing the same pattern as in figure 5 (b)

Conclusions

Measurements of crosstalk-induced dot placement errors were conducted with the Xaar1001 printhead printing in 3-phase mode. Careful design of the test equipment and choice of test parameters allowed measuring the dot placement with high accuracy. A set of 59 different test pattern were printed with up to nine neighboring channels on both sides of the monitored channel and including pixels from 4 earlier print cycles. The test data was evaluated in such a way that each individual pixel of the print pattern could be allocated a 'crosstalk weight factor' proportional to its effect on the drop velocity of the monitored channel. The largest crosstalk effect was exerted by the nearest phase neighbor channels, and they reduced the drop velocity from the monitored channel. The 'crosstalk weight factors' of the other pixels was typically one order of magnitude smaller, and they were partially positive or negative, i.e. that they increase or decreased the drop velocity, respectively. The test results further proved that the total crosstalk effect of large print pattern, as calculated by a linear superposition of the individual 'crosstalk weight factors' of the active pixels, was within 4% of the measured data. This allows to calculate the expected crosstalk-induced drop velocity changes and the dot placement errors of any arbitrary print pattern, and thus opens up the possibility to employ software techniques for modification of the bitmaps or develop specific driving waveforms to compensate for crosstalk effects.

The evaluation of crosstalk was further supported by measurements of the ink meniscus in the nozzle to monitor the meniscus motion and interpret pressure within the nozzle in real time. This provided the possibility to measure the pressure variations within printing and non-printing channels, and thus enable to monitor the 'pure' effect of crosstalk from neighboring channels.

Author Biography

Wolfgang Voit is member of the Advanced Application Technology group at Xaar. He received his diploma from the University of Applied Sciences in Regensburg, Germany. In 1997 he joined MIT Inkjet, Järfälla, Sweden, and Xaar in 1999. In the past 13 years he gained thorough experience in both inkjet printhead technology as well as developing new inkjet applications, specifically in the area of printing functional and non-conventional fluids for coatings and devices.

