Influence of the Rotation of Inkjet Printing Heads on the Print Quality

Christophe Mercier, Olivier Morel and James Fox - Xennia Technology Ltd, UK, and Ron Todd and Lindsay MacDonald - London College of Communication, UK

Abstract

In this study, we focus on the design specifications of industrial inkjet printers. In these systems, the printing heads are mounted individually on a carriage. The in-plane print head rotation has been identified as one of the reasons for the ink dots misplacement. This study aims to work out the influence of the angles of CMYK printing heads on the print quality. Ultimately, some mechanical tolerances are given to achieve different levels of print quality.

A two-step approach is used: one colour, then the four CMYK colours are considered. In the first step, a layout of the nozzles plate is used in a computer simulation. In parallel, a prototype has been built to validate the simulations. In the second step, a CMYK virtual printer is introduced in place of a four colours experimental system. A criterion on dots superposition is introduced to asses the influence of the heads rotation on the colour reproduction.

The nozzle plate layout has been added to a CMYK virtual printer to characterise the printing heads rotation. The model has been tested with XAAR 760 GS8 print head. Experiments are in a fair agreement with simulations for the one-colour approach. A cone angle for one and four colours has been derived.

Introduction

Nowadays, material deposition by ink-jet printing is used in a lot of applications, either graphical or non graphical. Both applications need to set the drops with a controlled accuracy in order to achieve the desired final quality in the allocated budget. The broad scope of the study is to link mechanical tolerances with print quality, and hence to get a relationship between cost and budget required to achieve a desired level of print quality. Among uses for this result, company may be interested in a better costs control/optimization at the design stage.

From the graphical side, the range of accuracy needed for ink deposition seems to extent itself up to 50 µm. If offset lithography print is considered, the lateral registration of the four colours has to less than 80 µm [1]. Burningham [4] studied the effect of the colour misregistration on the print quality, using an offset lithography press. A steep decrease in the print quality appears when the misregistration exceeds 50 µm. Belong 50 µm accuracy, it is expected that line blurriness and colour shift are present. However, in this range, the influence of the dots placement has not been fully quantified. Wencheng & al [8] has defined a model to assess line quality based on perception. However, the blurriness is not taking into account in his model. Svanholm [6] in his dissertation claims that there are strong correlations between both the colour gamut and print sharpness measurements, and the visual experience. Moreover, it is added that the smallest difference in print quality that could be visually discerned was approximately 350 units in gamut area, 1.6 µm in blurriness and 0.002 mm in line width. For non-graphical applications, like printing of micro-lenses [3], the dot positioning has to be as accurate as +/- 1 µm from centre to centre. In the case of micro-lenses printed over the vertical cavity surface emitting laser (VCSEL) emitters, the drop has to set on a pedestal, conditioning the dot drop placement.

From the other hand, from a mechanical design point of view, achieving a level of accuracy has a cost. Curves relating cost with tolerances [2], and machines are commonly used by mechanical designers. Commonly, as several models exist, the most common one is an exponential one. Several techniques are used to studies tolerances, among them Monte Carlo Simulations. There are based on individual assemblies using a random number generator to select values for each manufactured dimension, based on the type of statistical distribution assigned by the designer or determined from production data. These dimensions are combined through the assembly function to determine the value of the assembly variable for each simulated assembly. This set of values is then used to compute the first four moments of the assembly variable. Finally, the moments may be used to determine the system behaviour of the assembly, such as the mean, standard deviation, and percentage of assemblies which fall outside the design specifications.

In this case, the output of the model is the print quality. The print quality should be understood in the way defined by Engeldrum [1]: physical image parameters. Some attributes are defined in the standards [7] on print quality like edge raggedness, line width, uniformity, contrast which can be applied to either to a line or to a text. The print head rotation has been identified as one of the reasons for the ink dots misplacement. By example, the print head can rotate when the machined slot where it is mounted, is larger, in both directions, than the head dimensions. Linked to the study of the head rotation is the sensitivity of the nozzles layout to the rotation. As print heads differs by their resolution, nozzles layout, nozzle diameter, the appropriated choice is crucial of the design stage.

This study aims to work out the influence of the in-plane angle of printing heads on the accuracy of the ink deposition. The continuous effect of the head rotation, and not just a maximum acceptable angular deviation, is investigated. A link is established between the print quality and the placement. A two-step approach is used: one colour, then the four CMYK colours are considered. In the first step, a layout of the nozzles plate is used in a computer simulation. In parallel, a prototype has been built to validate the simulations. In the second step, a CMYK virtual printer is introduced in place of a four colours experimental system, too expensive to build. A threshold on dots superposition, based on the colour perception, is introduced to asses the influence of the heads rotation when printing with several heads, as in the colour reproduction.

Materials & Methods

Materials

An experimental printing system has been designed. The main part comprises the printing head fixed on a pivotable mounting. At one end, there is a pivot and at the other extremity a Vernier is used to convert lateral displacement into an angular rotation. A Xaar 760 GS8 Omnidot printing head has been used. The head consists of two rows of staggered nozzles. The nozzle pitch is 140 µm for a one row and 70µm when the two are considered. A photo-quality ink-jet paper has been used for the experiments. Lower quality paper featuring high spreading would cancel the pattern. Figure 1 presents the nozzles layout of a printing head with two rows of staggered nozzles.

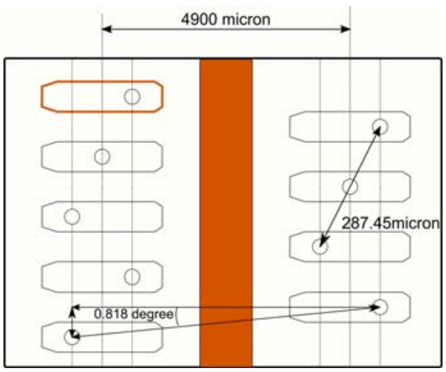

Fig 1: Nozzles geometry of the print head used in the experiment

Monte-Carlo model

A nozzles pairing appears when the printing head is rotated of a given angle. To evaluate this angle, the flowing formula (1), assuming of rotation around the nozzle, can use:

$$angle = atan\left(\frac{nozzle\ spacing}{Rows\ inter\text{-}distance + 2*Stagger\ distance}\right) \quad (1)$$

The following numerical values are used: the nozzle spacing is 70 µm, and the stagger distance is 23.5µm. For a distance of 4900 µm between the two rows, the angle is 0.81 degree. If that distance is 4200 µm, the angle becomes 0. 94 degree. For a head composed of one row with evenly spaced nozzles, the rotation of the head leads to a monotonous decrease of the distance between nozzles. For a print head with two rows, its rotation produces a periodic superimposition, with apparition of isolated nozzles at the extremities. If the image width is larger than the print swath, several passes are required. This implies a movement either of the head or the substrate, with a risk of misplacement. This leads either to white band or a over-density line. Several strategies are possible to manage the stitching area, from a nozzle pitch between the passes to several overlapping nozzles. The consequence on the stitching area is of importance as the distance between the dots will not be anymore constant.

Heads mispositioning can be decomposed as the combination of a rotation and lateral misplacements. Calculation can be done by using a referential centred on the middle of the head. A digital grid is used, where initially all the values are set to zero. The ink dots, with an assumed constant thickness, are then added, giving a stairs-like shape, corresponding to the different levels of inks superimposition.

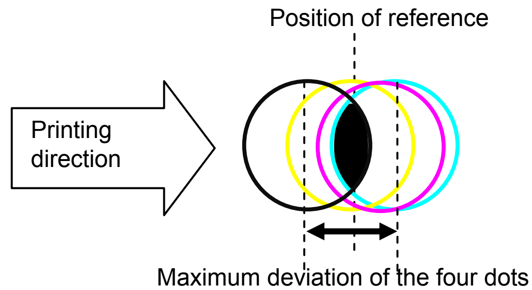

Fig 2: Common area, in black, derived from the CMYK dots superimposition

A random numbers generator is used to generate the centre of fours dot. A Gaussian distribution is used with a mean of zero, the standard deviation representing the spreading around the ideal reference. Then, the maximum distance between the dots is computed to get tolerances. The percentage of superimposition is calculated for each configuration by comparing the number of pixels at the maximum level with the number of pixels corresponding at the original dot size, as presented figure 2.

Results

The influence of the in-plane print head rotation can be assessed visually when using one colour printing. Effects at macro-levels are presented. With four colour printing, the isolated influence is more difficult to point out as several parameters may perturb the interpretation.

One colour

Figures 3 and 4 shows printed results for a line and for text, with one pass. The print direction is vertical, from the top towards the bottom.

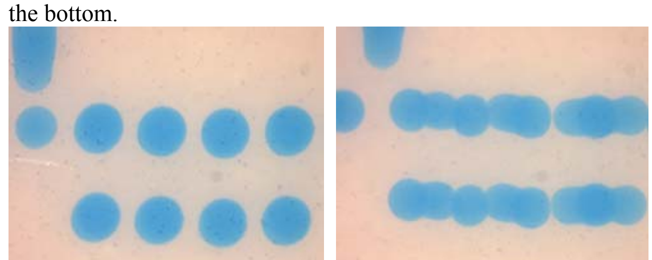

Fig 3: Influence of head rotation on line connectivity (left), maximum rotation, (left) minimum rotation

In a perfectly aligned head, with a correct synchronisation between the two rows, the inks dots form a perfect line, presented figure 3 (right). Once the head is rotated, the synchronisation is lost, creating bigger dots, as shown figure 3 (left).

By printing bigger dots, the chance of making them visible is increased. As the printed line quality is damaged, the print text quality is also lowered, as figure 4 (left) shows. The relationship between text readability and print text quality is not investigated here. As the distance between the equivalent dot increases, or real printing resolution decreases, as seen, up to two times, the maximum optical density will also be lowered. Colour correction, usually done by ICC profile, will be ineffective in correcting this issue.

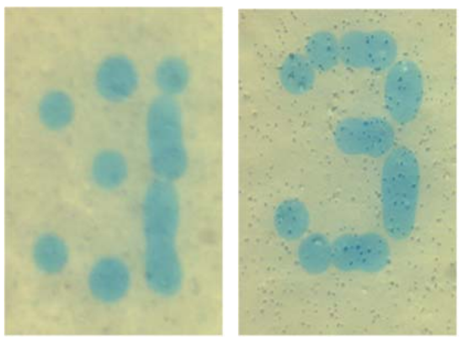

Fig 4: Influence of head rotation on text reproduction: (left), maximum rotation, (left) minimum rotation

In a printing head consisting of one row of nozzles, the printing resolution increases as the head angle increases, and in monotonous fashion. Here, the resolution changes in a periodic way. Thus, for twice 0.81 degree, the printing resolution is 360 dpi.

n colours

The rotation of the printing heads influences also the ink dots superimposition. The last nozzle is considered in your experiment, as presented is figure 5.

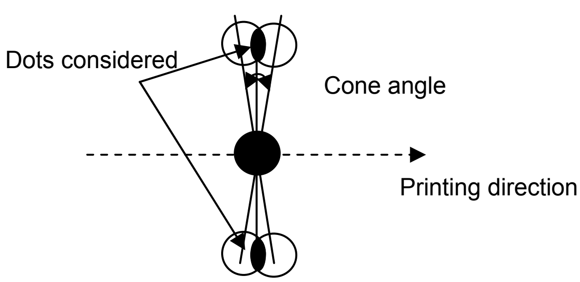

Fig 5: Overlapping area for the extremities nozzles: (left) cone of tolerance, (right) resulting curve

The model presented figure 2 is used for the last nozzles of the print head. Only the translation is considered here. By generating four head angles from a random Gaussian distribution, the overlapping area can be estimated. From the figure 6 (left), the head angle, to statistically get the superposition between the dots has to be less than 0,1 degree.

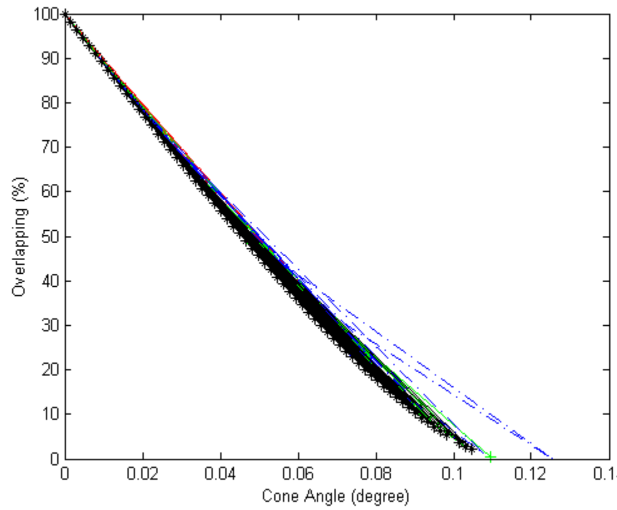

Fig 6: Overlapping area for the extremities nozzles in function of the cone of tolerance.

For graphical application, it can useful to drawn a relationship between the cone angle done by the four print head and a variation a colour. By using a colour model, it is possible to link the ideal colour of a dot and the actual colour. The result takes into account the dots superimposition and the distance between their centres as presented figure 2. By increasing this distance, a curve linking Delta E, in the system CIELab 1976, and the percentage of overlapping is plotted. Then the Delta E is linked to the cone angle thought the percentage of overlapping. By example, for a Delta E of 6, the estimated overlapping is 75%, which leads to a cone angle around 0.02 degree.

Conclusion

An experimental set-up has been built to produce samples with a controlled printing head angle. Indeed, producing samples is the only way either to conduct visual quality assessment or to measure the optical density. In the study, we have shown that increasing the distance between the two staggered rows decreases the mechanical tolerance for the printing heads mounting.

By decomposing the CMYK print heads misplacement, in a rotation and a series of translation, and focusing on rotation, a curve relating cone angle and percentage of superimposition has been shown. For a delta E of 6, the estimated cone angle is 0.02 degree.

The printing head angle is not the only the parameter involved in the drop placement accuracy. In order to replicate the behaviour of a printer, further developments have to be integrated. Hence, the throw distance, the substrate speed, or the jet directionality are to be add to the model.

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Bibliography

Dr Christophe Mercier *joined Xennia Technology Ltd as research and development engineer. He is the author of papers in paper and printing sciences. He received his PhD in paper physics from the Institut National Polytechnique of Grenoble (France).*