Print quality requirements for single-pass inkjet printing – the whole picture

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The subject of print quality is an area which is very complex, subjective and difficult to quantify, particularly when printing four colour images[1].

Some recent articles in the printing trade press have proposed that the number of dots or lines that can be printed per inch (dpi or lpi) and the native nozzles per inch (npi) of an inkjet printhead are key determinants of final print quality. This is a simplistic position to take and does not consider the many other factors which determine final print quality.

A decision based on this criterion alone would dismiss offset litho, seen as the benchmark for print quality for decades. Printed at 150 lines per inch, offset would not compare on this measure to inkjet printheads with 360 or more nozzles per inch.

When considering inkjet printing, image quality involves complicated interactions among many elements including the printer, printhead, substrate carriage system, printer driver/RIP, inks, media and viewing distance. **Figure 1** below, illustrates an example of a digital printing process and a summary of the determining factors of quality.

The aim of this article is to give a fuller understanding of the determinants of print quality and how it is perceived, particularly with relation to the printhead, and to show that it is not simply a case of selecting the highest number, be it dpi, lpi or npi.

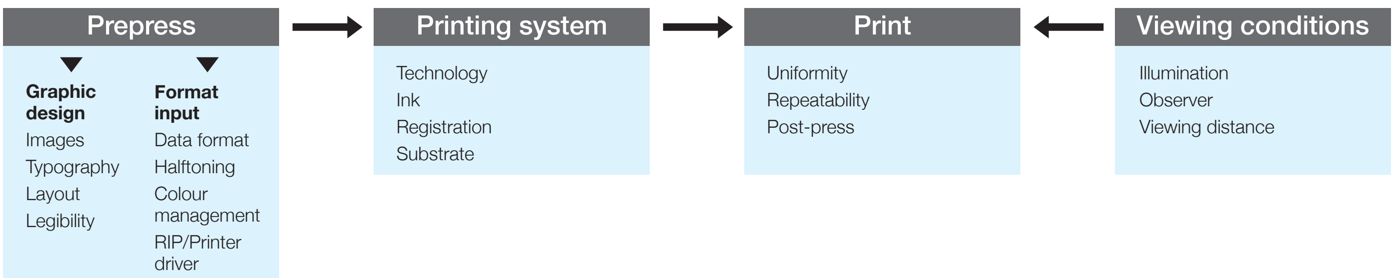

Figure 1: Factors determining print quality in digital printing processes

Print resolution

The term print resolution refers to the capability of a printing system to reproduce image detail[2,3]. It is assumed that the finer detail a printer is able to reproduce, the higher the print quality will be perceived. This sounds quite straightforward; however in practice print resolution is more complex and cannot be quantified by a single measure.

In general, two major sets of factors dictate the detail that can be reproduced by a printer:

- Quantitative factors, such as the npi of a printhead or dpi of a print system, also known as addressability
- Qualitative factors, or resolution, which define the level of sharpness and contrast.

Addressability is a characteristic of a printhead or array of printheads, whereas resolution is a factor of the drop size and relates directly to the perceived quality as seen by the human eye.

When considering the overall performance of a printhead its npi, minimum drop size, sub-drop size, number of available greyscale levels, uniformity of drop volume, drop placement accuracy and integration into a print system all play a significant role. It is also important to note the fact that perceived print resolution is dependent on the viewing distance, contrast, and on the viewing conditions[5,6]. When talking about resolution, the whole system must be considered, and this includes the person who is viewing the image. High resolution capability is of no benefit when it is beyond the capacity of the human eye and visible only through the artificial use of magnification[6].

Understanding dots per inch (dpi)

Inkjet printheads are often characterised by their nozzle density or nozzles per inch (npi), for example the Xaar 1002 has a density of 360 npi. This is also called native addressability, and can be described as the rectangular grid of possible printable dots defined by the nozzle distance along the axis of the printhead, and by the linear speed and print frequency in the axis of the media motion (see **Figure 2**).

However, to characterise a printer it is important to take into consideration the effective addressability of the device, not just the native addressability of the printhead[3,4]. Effective addressability is the smallest, consistent, incremental distance by which a printer can shift from the centre position of one printed point to the centre of its neighbour. When the encoder resolution is increased on the media axis, this also increases the effective resolution, which in turn will influence print detail (see **Figure 3**).

Addressability can also be increased by interleaving multiple printheads to double the effective npi, or by mounting printheads at an angle (see **Figure 4**).

The flexibility of the Xaar 1002 printhead enables it to be integrated into print system designs in a choice of these configurations appropriate to the requirements of the end application.

The native addressability or npi value of a printhead thus identifies a location of dots, but does not actually describe the real print resolution, or size of the printed dot.

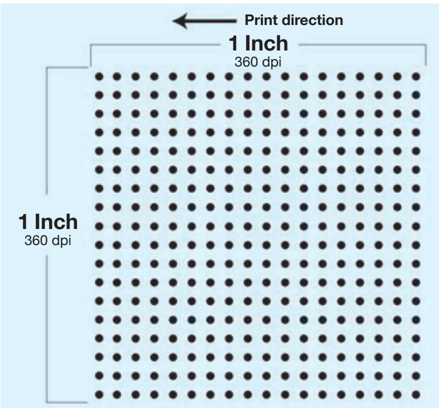

Figure 2: Native addressability of Xaar 1002 printhead at 360x360 dpi

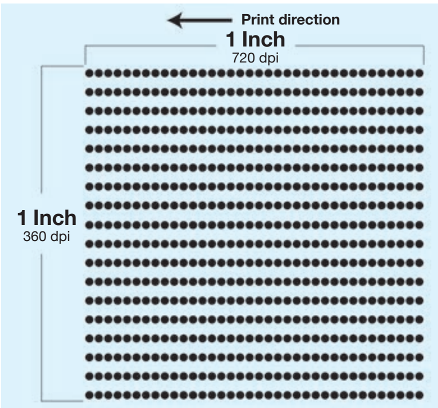

Figure 3: Xaar 1002 printhead with encoder resolution increased to give 360x720 dpi

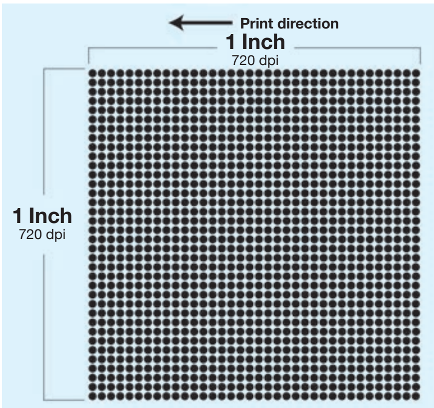

Figure 4: Xaar 1002 printheads interleaved to give 720x720 dpi

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Variable dot greyscale technology

The spatial measure of resolution of dots per inch (dpi) is only relevant when measuring single or binary droplets. The use of variable dot greyscale technology in a process colour image increases the apparent or effective resolution visible to the human eye, and renders the term dpi meaningless as a standalone measure.

The number of grey levels can be defined as the number of different dot sizes it is possible for a printing process to reproduce, including white, where no dot is present.

Offset litho using a 2400 dpi plate at a screening frequency of 150 lpi will produce a minimum of 256 grey levels. This ability to print a large number of grey levels is one of the major reasons that offset print quality is high, despite its relatively low printing frequency.

Using variable dot technology, the Xaar 1002 GS6 printhead can produce seven different sizes of drop between 6 and 42 picolitres. This means that the Xaar 1002 GS6 is capable of printing 8 grey levels.

To achieve clean edges on graphics and text, especially on diagonals, a high print resolution is necessary. **Figure 5** shows how the variable dot size can be used to clean up edges on fine text so that its smoothness is improved.

Figure 5: Use of greyscale to improve fine text

With flat tints, where the aim is to have a smooth appearance without texture, the wide range of ink drop sizes available enhances the final printed image.

The 8 grey levels of the Xaar 1002 GS6 are set at linear increments of 6 picolitres which means that the printed dots are clearly differentiated in size. This ensures that a wide range of tonal values, from very light shades, through mid-tones, to full solid coverage can be achieved.

If drop volumes and therefore dot sizes are too close, printhead tolerances will often result in identical dot sizes. It therefore becomes impossible to differentiate tonal differences resulting in a greyscale range which is in reality narrower than the product specification states.

Figure 6 below illustrates two examples:

a) Xaar 1002 GS6 at 360 npi with 8 grey levels at clearly differentiated linear 6 pL increments

b) 600 npi printhead with non-linear increments and barely differentiated dot sizes: greyscale effectively reduced from 5 to 3 levels

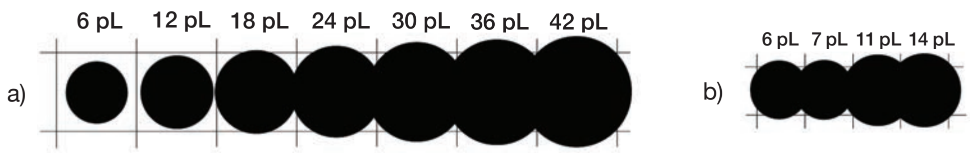

Figure 6: Comparison of dot sizes

Effective or apparent resolution

The terms effective or apparent resolution are often used when referring to the perceived resolution of a printed image using greyscale technology. The capability of varying dot size line by line and pixel by pixel results in a higher perceived print resolution than the basic printhead dpi specification. The more levels of visible greyscale, the smoother the colour transitions become, resulting in a level of print quality comparable with high dpi binary or restricted greyscale images.

Effective resolution can be calculated by: $dpi\ x\ \sqrt{number\ of\ grey\ levels}$

Some examples with different printhead dpi and greyscale levels are illustrated in **Figure 7** below.

Printhead npi	Greyscale levels	Effective resolution dpi
360	8	1018
600	5	1341
600	2	848
720	4	1440

Figure 7: Effective resolution

The Xaar 1002 GS6 printhead with a native 360 npi and 8 clearly differentiated grey levels, results in an effective resolution greater than 1000 dpi. This is further increased if used in 720 dpi mode even with a greyscale restricted to 4 levels.

However a higher npi printhead with just 2 grey levels will result in a lower effective resolution as can be seen with the 600 npi example in **Figure 7.**

Figure 8 below shows a simulation of a 360 dpi four colour image using 8 grey levels compared to another at 600 dpi using 2 grey levels. These were imaged using Adobe Photoshop, Xaar plug-in and identical screening patterns. This illustrates that the wider greyscale range of the 360 dpi image results in smoother colour transitions which compensate completely for its lower native addressability.

Figure 8: Digital image simulation of 360 dpi with 8 grey levels compared to 600 dpi with 2 grey levels

Viewing distance

The ability of a print system to achieve high effective resolution is one factor of perceived print quality. Ultimately it is the capability of the human eye which is the final determinant, and this is governed by the distance from the eye to the image – the viewing distance.

The resolving power of the average 20/20 adult human eye, commonly referred to as normal visual acuity, is considered to be one arc minute (a unit of angular measurement equal to $1/60^{th}$ of one degree)[7]. This translates to a dot size of 29 microns at the eye's closest focusing distance of 10 cm (4"). This in turn equates to an effective resolution of 876 dpi – well within the capabilities of a 360 dpi 8 grey level printhead.

Resolving power decreases with an increase in distance so that at the average reading distance of 30 cm (12"), the finest resolution that the eye (at one arc minute) can perceive under ideal viewing conditions is 89 microns or about 300 dpi.

Resolving power also diminishes based on other variables such as iris diameter, light levels, contrast, and light wavelengths. This means that the minimum effective resolution or dpi level required for a specific viewing distance will normally be at the high end for 20/20 vision (see **Figure 9**).

This is why magazines are printed at 300 lpi and most computer monitors have about 100 pixels per inch (ppi) – these resolutions are more than good enough at the correct viewing distance even in ideal lighting conditions. The chase for higher numbers which are not visible with the naked eye is just that – a chase.

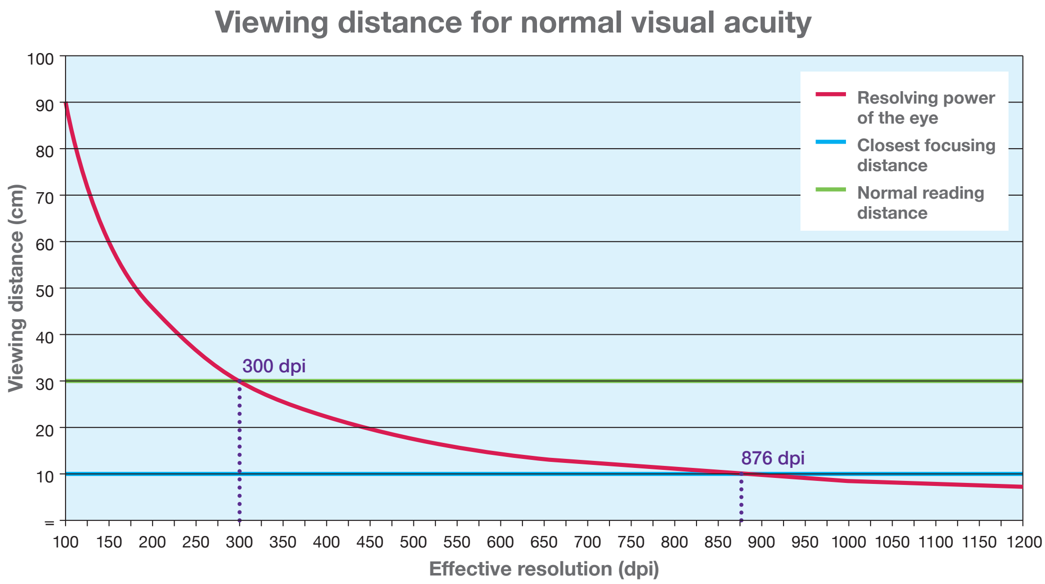

Figure 9: Viewing distance versus effective resolution

Dot size

The size of a printed dot is a function of the drop volume jetted by a printhead and is influenced by the ink and substrate characteristics. A smaller drop size gives a smaller printed dot which results in a lower colour density, thus improving image highlight areas.

However, this does not necessarily mean that smaller is better. An array of printed dots which do not fully overlap and have white space between them will not be suitable for printing solid areas or bold text. A larger dot size can ensure that full solid coverage and stronger or higher opacity colours are achieved. This is a distinct advantage for prints that are designed to have a high visual impact.

Figure 10 shows two versions of the letter 'X', both made up of the same number of dots, but where the dot size of the image on the left is twice that of the one on the right. The smaller dot 'X' has areas of white space which results in a lower colour density and a lighter shade. This is particularly clear when viewed at a distance where the individual dots are no longer visible and illustrates how dot size can play an important role in the perception of the final printed image.

Figure 10: The effect of dot size on colour density

The Xaar 1002 GS6 printhead can jet drop volumes as small as 6 pL which results in small dot sizes that are ideal for the reproduction of highlight image areas. Its greyscale capability also enables it to jet drop volumes up to 42 pL which are suited to the creation of striking colours and highly opaque whites. This single printhead variant can therefore cover the print quality requirements of fine detail images as well as strong, vivid colours.

Dot placement accuracy

The basis of all print imaging is the accumulation of dots at specific points on a substrate which create lines, solid areas or halftone patterns. If there are differences between the intended position of the dots and their actual position, image quality artefacts will result.

To ensure precise imaging, each printed dot must be placed in the exact predetermined position on the substrate. An error from this position directly affects the quality of features such as lines and text exhibiting 'ragged edges', and can also affect colour registration, resulting in white lines in images or solid areas (see **Figure 11**).

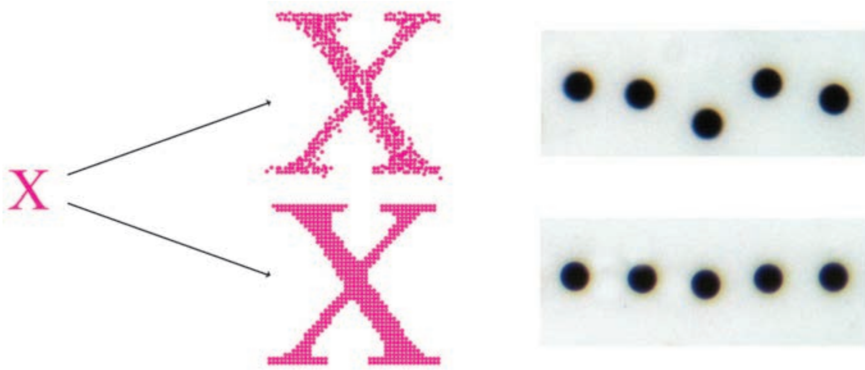

Figure 11: Effect of dot placement accuracy on text reproduction

Along with the precision of the substrate carriage of the printer, the drop placement accuracy of the printhead plays an important role in the final print quality. All printheads are manufactured with a tolerance for the drop placement accuracy of every nozzle in the printhead. This will determine the initial capability of a printhead when first installed.

The Xaar 1002 family of printheads uses Optimised Geometry nozzles to deliver extremely precise drop placement accuracy and consistent drop volumes even with heavily pigmented and high viscosity fluids. This ensures accurate reproduction of fine text, along with exceptionally smooth print tones and solid areas across the printhead and the entire print width.

However, in the real world, air bubbles or particles which find their way into the ink chambers of end-shooter type printheads can cause deviated nozzles or misdirects which can only be removed by regular maintenance and in extreme cases by replacing the printhead itself.

Xaar's unique TF Technology™ and Hybrid Side Shooter architecture used in Xaar 1002 printheads ensures continuous ink flow at a high rate directly past the back of the nozzle during drop ejection. This means that any air bubbles and unwanted particles present in the fluid are carried away. This radically improves jetting reliability and reduces the likelihood of temporary or permanent nozzle deviation.

Dot size consistency

Visual print quality can also be affected by the consistency of drop volume, and therefore drop size and ink thickness across the print width. Bands of different colour density visible in the image in the print direction are highly undesirable, but can result from inconsistent drop volumes across a single printhead width and, where there is variation from printhead to printhead, across the entire print width.

Consistency of drop size is influenced not only by the physical capability of a printhead to jet drops of equal volume, but also its ability to regulate and manage the heat that builds up through the process of actuation. A variation in ink temperature will affect its viscosity, and thus the drop size which will be ejected. A higher temperature in one area of a printhead will result in a higher drop volume and increased density of print which can be extremely difficult to manage.

The Xaar 1002 was developed to have best-in-class parametric performance for consistency of drop volume across the printhead which has resulted in an extremely flat and repeatable drop diameter profile. In addition, constant recirculation of ink, achieved through the use of TF Technology™, ensures that ink temperature is always controlled and provides the thermal consistency which results in even colour density across each printhead and the entire print width.

Printing in real life

Figure 12 below shows actual results from 3 inkjet label presses each with different effective addressability: 360, 600 and 720 dpi. All were printed using the same original artwork, identical prepress software, and on the same substrate type. The images were scanned at 3200 ppi and are reproduced here at actual size (row 1) and with part of the image at 2x magnification (row 2).

These show no significant difference despite the different native addressability of the printheads. In fact, it could be argued that the lowest native resolution 360 dpi gives the most legible results, especially in areas of reverse text.

1)
2)

a) b) c)

Figure 12: Identical images printed with effective addressability of: a) 600 dpi b) 360 dpi c) 720 dpi

Note: All images printed on HERMAwhite Super (240), using Esko Suite 12 prepress software and identical original artwork. Scanned at 3200 ppi with all automatic functions and corrections turned off and saved in a TIFF lossless bitmap format.

Summary

This article has determined how to: distinguish between native and effective addressability; explained the value of greyscale technology and clearly differentiated drop sizes; highlighted the importance of dot placement accuracy and drop size consistency; underlined the role of viewing distance and the resolving capability of the human eye in relation to the perception of print quality.

It has shown that there are many important factors which influence the final quality of a printed image. To reduce the measure of print quality to a single parameter, such as the native addressability of an individual printhead is too simplistic, and results in a one-dimensional perspective of a highly complex subject.

It is also essential to note that the focus of this article has been on the role of the inkjet printhead in achieving final print quality. Other influential elements, such as print carriage accuracy and consistency, ink and substrate types, throw distance between printhead and substrate, RIP and half toning software, etc. have not been considered in the scope of this paper.

In conclusion, this investigation into the key determinants of print quality clearly shows that no single factor can decide the final print quality. It has demonstrated that there are many contributory factors, and it is the combination of these that will result in the final perceived print quality of an image.

References

1 Pedersen M.: Image quality metrics for the evaluation of printing workflows, PhD thesis, Faculty of Mathematics and Natural Sciences, University of Oslo, 2011

2 Kipphan, H., Handbook of Print Media: Technologies and production methods, Springer-Verlag Berlin Heidelberg New York, 2011, ISBN 3-540-67326-1

3 ISO/IEC TS 29112: Information Technology – Office equipment – Test charts and Methods for Measuring Monochrome Printer Resolution, 2013

4 Zeise E. K., et al.: Measurement of contributing attributes of perceived printer resolution. in Image Quality and System Performance VI. 2009

5 Campbell F. W., and Robson J. V.: Application of Fourier analysis to the visibility of gratings, Journal of Physiology, p. 551-566, London, 1968

6 Sigg F.: Test targets 6.0. In School of Print Media (CIAS) – Test Targets, chapter Testing for Resolution and Contrast, p. 1–5. RIT, 2006

7 Blackwell, H.R.: Contrast thresholds of the human eye, Journal of the Optical Society of America, vol.36, Issue 11, pp.624-632, 1946

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Issue 4 January 2015