From Application to Resolution

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Abstract

In the ink-jet industry, we see more and more the trend adopted by printer vendors to implement higher resolutions in their printers, suggesting that this is what gives the prints a better quality. The authors address this issue in a methodological manner, suggesting a practical approach to defining the necessary printer resolution for a given application.

Focusing on industrial applications, the article describes the decision process of choosing the right print resolution for the right application on the printing machine, using both theoretical and practical considerations. The proposed step by step process, guides the product architect to taking into consideration various factors and putting them all together as design guides for the ideal printer for any application. Human factors, such as eye visibility, alongside printer factors, such as dot placement accuracy, cost, throughput, data overload and ink consumption are all integrated into the methodological approach.

In order to get the best cost performance ratio for an industrial printer, ink-jet print heads may be better optimized for a completely different working point than what current head vendors are actually offering. The challenge of meeting industrial high throughput demands at relatively low cost and with proper image quality has been shown to dictate a working point that calls for a dedicated head design matched for industrial printing applications. Such a print-head is under development and shown to meet the set of requirements dictated by the system design process.

Introduction

In the past few years, industrial printing is showing a very aggressive shift towards digital printing. New applications are emerging, challenging the digital printer designers to achieve ever higher quality at affordable costs, with the ultimate goal to take a significant share from the analog methods. With the demand for higher throughputs, the designers are facing a conflict between the desire to achieve this high throughput and the need to offer competing quality of the final print and at reasonable cost. One "simple" solution for achieving high quality print is to enhance the printer resolution and offer 600 dpi or even higher. The problem with such an approach is that the cost of the printer is significantly increased and the throughput is decreased. In this paper the author is offering a systematic approach to find the cost effective printer resolution for each application. Interestingly enough, it turns out that the "right" resolution also assists in achieving an optimum in ink consumption.

What is resolution:

Definition starts by identifying two important terms, eye sensitivity and printer resolution. Both refer to the general concept of resolution.

Eye sensitivity- The ability of the human eye to resolve details is a function of contrast and viewing angle. The higher the contrast is, the higher the sensitivity. Per a given value of contrast, the eye sensitivity to details varies with frequency. The eye contrast sensitivity function is described in fig. 1 for two different values of contrast (note that it is described as a function of cycles per degree, namely the angular separation of a pair of lines – black and white).

This function is a result of statistics since different human observers have different sensitivities.

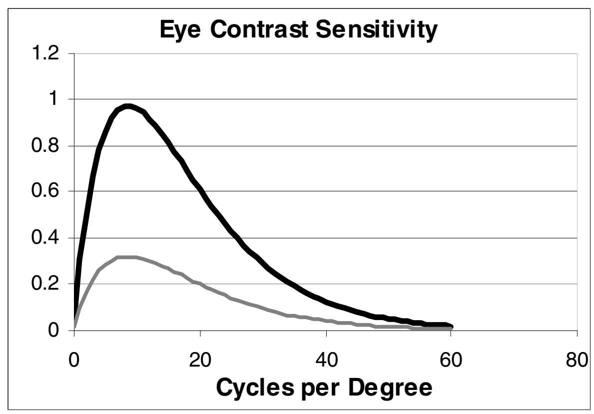

Figure 1. Normalized eye sensitivity to contrast as function of viewing angle.

Ideal printer resolution - The ideal printer resolution is the physical size of the printer logical pixel, the theoretical X/Y grid which dictates where dots are supposed to be printed.

These two resolution concepts relate to each other in the following way: On a printed image, each pair of pixels form a spatial cycle. Given a viewing distance, one can transform the spatial frequency into angular frequency and use the chart in figure 1 to determine sensitivity. In order to understand what should the ideal printer resolution be for a specific application, additional terminology is required.

Viewing distance - Viewing distance is the distance between the observer and the print. As opposed to home or office applications, industrial applications are characterized by longer viewing distances. Ranging from 50cm for fine displays (or POP) to tens of meters for Billboards.

The observer - Observation characteristics also differ, as in home and office the observer reads the printed page, this requires concentration so even minor deficiencies are irritating the observers eyes. In the case of POP or displays, the eye flies across the printed object and does not dwell on the fine details. Different people have different sensitivities to the details and thus, may position a different threshold on the sensitivity chart (given in figure 1). The authors believe that a threshold at 10% (one tenth of the maximal sensitivity) is a good balance between standard observers who do not pay high attention to the print fine details and the professionals who will look for the very fine details.

Image quality - Image quality is a very broad concept. For the sake of our discussion, we will simplify this concept and address two measures: fine details, best represented by text font, and light areas of the image where single dots printed create grain effects. It is known in the industry that even for moderate levels of resolutions, light colors suggest a proper solution to the graininess phenomenon as they have less contrast (see lower curve in fig.1). The real challenge to the resolution comes from the fine details in the image (e.g. text).

Font quality - Good quality font must be formed in a rectangle of at least 20x15 pixels of the ideal resolution (see figure 2).

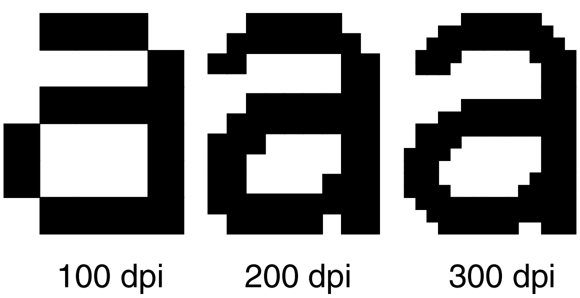

Figure 2. 6 points character reconstruction by 3 different resolutions.

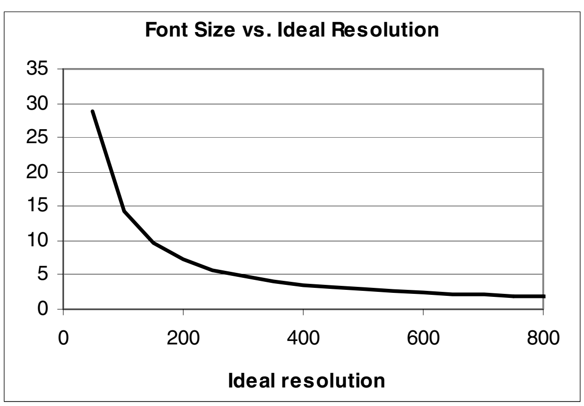

Figure 3 .Font size formation as function of resolution.

This amount of pixels is able to preserve the original font shape as well as cover digitization errors (again, for printed documents, one might require a finer division). For an ideal printer, one can now plot the minimum quality font size that can be obtained on an ideal printer against the ideal printer resolution, as defined above. This is given in figure 3.

Putting it all together

The ideal printer

Step 1: Select the appropriate viewing distance for the intended application. As an example we will use 50cm for POP application.

Step 2: Define your standard observer. In our example we will use the threshold of 0.1 - leading to 42 cycles per degree in fig 1 above.

Step 3: Draw the chart of viewing distance against ideal resolution by using the number obtained in step 2, i.e. 42 cycles per degree and the relation between resolution and viewing distance as defined by the viewing angle of a single cycle. Example of this chart is given in fig 4 (bold line for sensitivity 0.1, 0.01 - 59 cyc./deg. and 0.5 – 23 cyc./deg.). Following the example it is seen that at 50cm viewing distance we will need about 250dpi ideal resolution.

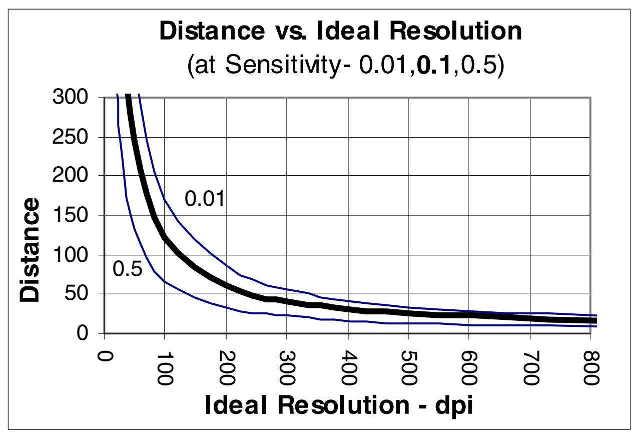

Figure 4. Distance vs. resolution using 3 cycles per degree values.

Step 4: Using the criterion of 20 pixels square for quality font reproduction we can refer to figure 3 to observe what is the minimal font for the ideal resolution. If we follow again the same example, we can see that 6 point font can be reproduced.

To summarize it, the ideal resolution required to provide quality images viewed from 50 cm aimed for industrial POP applications is 250 dpi.

The real printer

Real printers are not ideal. They suffer from inaccuracies as well as from physical and inherent digital phenomenon that must be taken into account. To start with, printed dots are far from matching rectangular pixels. They can be round, elliptical or even some other distorted shapes. So, even for very nice behaved dots, one must make the dots bigger by a factor of 1.4 ($\sqrt{2}$).

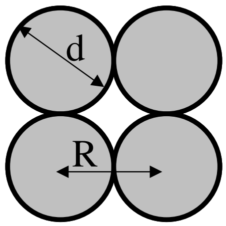

Figure 5. Dots at the size of resolution grid create voids.

Figure 5 illustrates that unless the dots are made bigger, voids will be inherent in the printout, forbidding solids to be created. On top of that, there are many printer inherent inaccuracies all resulting in errors in the dot placement. Such inaccuracies can come from media advance errors, from aerodynamics of the drops reaching the media, from built in errors in the inkjet heads and even from dynamic effects of the liquid drops on the media before fixing. For all these reasons, the ink dots on paper must be made bigger in order to create full solid without voids. Increasing the dots will result in loss of details, so when compensating for errors one must increase the print resolution in order to get the same output representation of the details.

The chart in figure 6 maps different levels of inaccuracies of the ideal printer resolution against the real one. In this specific chart, dot placement errors of 20 (top curve), 50 and 75 microns are considered. Referring back to the very important example that is followed. So far, the conclusion is that 6 point fonts on a POP type of application leads to ideal 250 dpi resolution. When real printer effects are added to the equation, as discussed above, we can see that for the examples of inaccuracies and for maintaining the required ideal resolution of 250dpi, a printer resolution of anywhere between 275 dpi to 400 dpi is required!

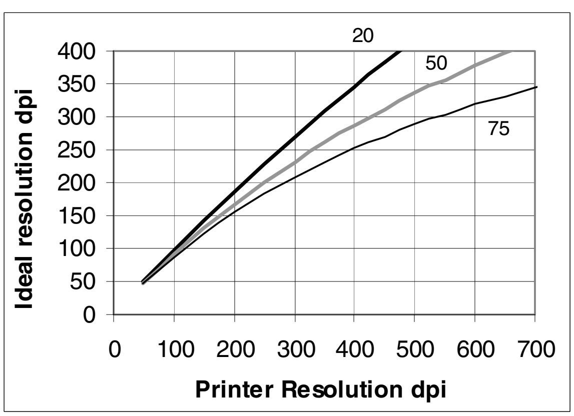

Figure 6. Ideal resolution vs. printer resolution , the result of inaccuracy.

From an engineering point of view, it is not recommended to design without some preparation for the unexpected and thus, we should add safety margins of about 50%. As a result, one can see that for our example of 6 point font viewed from 50cm distance, one must design the printer resolution to be anywhere between 400dpi to 600 dpi, depending on the accuracy of the printer. The cost and throughput differences of two printers, designed for these two extremes, is very significant. The authors therefore highly recommend to invest in reducing the inaccuracy levels as the payback may be well worth it.

Ink consumption considerations

So far, we have considered the cost of the printer only. We have seen that quality requirements dictate that the ratio between dot size and addressability must be increased in order to be able to cover voids in the printout. Obviously, there are two ways to deal with it. One is to increase the dot size and maintain the addressability – This will lead to reduced quality as fine details will be lost. The alternative would be to go to finer addressability for the same dot size and thus change the ratio between the two. One must recognize, though, that going either way leads to higher ink consumption. That is, on the micro level, ink densities will change significantly, depending on the local accumulation of errors. The chart in figure 7 depicts ink consumption against addressability for the same three levels of printer inaccuracies. It is interesting to note two effects in this chart. One obvious effect is that for the same addressability, ink consumption is reduced dramatically for higher accuracy printer. The other effect is that when lowering the levels of inaccuracies, the point of minimum ink consumption is moving to higher resolutions but also the curve becomes flatter. That is, the ink consumption is less sensitive to the selected resolution working point. It should be noted here that unlike the discussion on geometrical effects above, where the numbers are reliable and reflect real life results, the picture with the ink consumption is less accurate and should only be used as a guideline. The reason for that is that ink drops on paper take various 3D shapes depending on many of the liquid fluidic parameters. Therefore, simulating real life ink consumption is more tricky and requires sophisticated models. In the calculation drawn above, we have taken a relatively simple model. Yet, the qualitative indication remains correct.

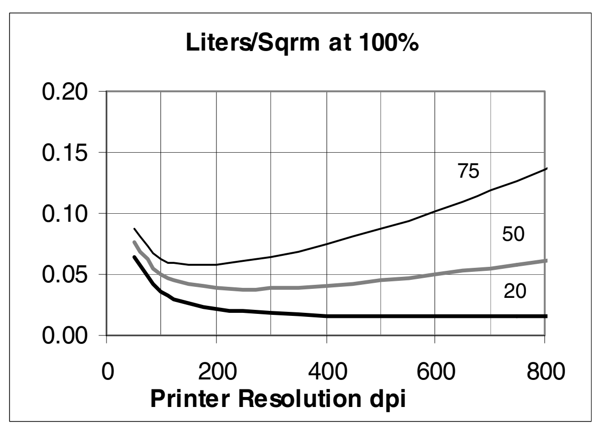

Figure 7. Ink consumption vs. printer resolution with different inaccuracies.

Numerical example

In order to demonstrate the essence of the article a numerical example is needed. A reference calculation is taken of a machine designed for 400 dpi having the accuracy of 50 microns. Two alternatives are available in order to improve quality. One is to increase resolution to 600dpi and the other is to stay at 400 dpi but improve accuracy to 20microns. In the table below the first line represents numerical data relevant to the reference machine while the other two lines represent the characteristics discussed above.

	Print rate [m²/h]	Data rate [Mb/s]	Nozzle cost [$]	Lamp power [norm.]	Ink coverage [m²/L]
400 -50	121	17	4800	1	24
400 -20	121	17	4800	0.8	51
600 -50	83	27	7200	2.1	20

The table shows that the right choice is in improving accuracy as it is advantageous at all critical parameters.

Conclusions

A systematic approach to selecting design parameters of a digital printer is drawn. Given the fact that the cost of both throughput and resolution are very high, one must carefully consider the target application of the printer and drive to the lowest possible resolution, without sacrificing the quality requirements. It is also shown that there is significant payback in making more accurate printers and that the cost savings come from both printer cost and ink consumption. An example was shown that for a relatively demanding application of 6 point font on POP one can end up in an increased resolution of 50% to compensate for mere 30um printer inaccuracies. In the author's experience, a significant contributor to dot placement inaccuracies is the print head. The advice, then, is to invest a lot in making better and more accurate heads. If a good job is done here, one can save a lot on the printer level and use significantly less nozzles at lower resolutions and thus save a lot also in terms of ink consumption.

Bibliography:

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Author Biography

Mr. Eyal Gargir has B.Sc. in Electronic Engineering from Tel-Aviv University in Israel. Eyal Gargir has joined Scitex Corporation in the early 80's. Starting in 1986, Mr. Gargir has participated in developing laser plotters, one of which, The "Dolev", was awarded the Rothschild prize for excellence, in 1992, by the Israeli Ministry of Industry & Commerce. In 1993 Mr. Gargir joined the Scitex ink-jet development team that later became Aprion. Ever since, Mr. Gargir is specializing in print quality starting in Aprion, then Scitex Vision and currently as a member of the HP family at HP Scitex. Mr. Gargir has 4 patents in the domains of print quality and inkjet.