Printer Calibrations for HP Large Format Page Wide Technology

Martí Rius, Marc Casaldàliga, Xavier Fariña Vargas, Xavier Quintero, Romà Segura; Hewlett-Packard Española; Sant Cugat del Vallès, Barcelona (Spain)

Abstract

We present the main printer calibration procedures for HP Page Wide XL 4/8000 page wide array (PWA) printer. They ensure consistent, uniform printouts by calibrating print elements to each other, both for relative positioning and relative colorimetric densities. Requirements for (PWA printers are much stricter than for scanning printers, and for that, new solutions have been devised.

Furthermore, in large format PWA printers there are more restrictions for the carriage subsystem that include the calibration sensors, so that the trajectory of sensors relative to the calibration patterns is less accurate than in scanning printers. We present the new print-head alignment strategy and detailed patterns innovations to overcome the challenges in scanning trajectory and at the same time meeting the precision requirements. Innovations comprise the use of new position based patterns, to obtain a fast and wide error range ¨coarse grained¨ measurement, in combination with high precision interferential patterns that refine the final measurements.

Colorimetric calibration includes novelties such as using floating references to make sure almost all available media can be calibrated, in opposition to past calibrations that used references defined in absolute domains. Furthermore, it incorporates means for reusing a calibration run on a given paper to the rest of paper types loaded in the printer. All of that ensures maximum color deltas between adjacent print elements in the order of 0.5dL, with percentile 95 in the order of 0.2dL* (data obtained in selected paper types).*

The solutions for the problems derived from the incompleteness of calibrations when the media used does not cover the full printing region are also presented. To enable a satisfactory user experience in a variety of media usage scenarios in a multi-roll printer a number of innovations have been introduced, ranging from the use of print-head module manufacturing data to the optimal selection of the media roll to calibrate when different media qualities and widths rolls are loaded in the printer.

The presentation covers the basic concepts of print-head positioning and colorimetric calibrations, and then reviews novel solutions adopted in HP page wide array technical printers.

HP Large Format Page Wide print systems and calibrations overview

In 2013, HP introduced HP PageWide Technology in a high-performance family of desktop multifunction printers: the HP Officejet Pro X-Series. In 2015, with the introduction of HP Page Wide XL Series, the technology has been extended to 40in-wide Large Format printers, which can now print up to 30 A0/min full color at 1200 dpi resolution.

At the core of the technology lies the print-head module comprising 6 HP Thermal Inkjet chips –called dies, each one with 4 rows of 1056 nozzles (that deliver CMYK in the color configuration) and pitched at 1200 dpi (see Figure 1)

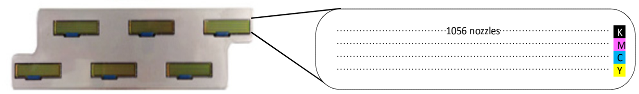

FIGURE 1
This print-head module is designed to be stacked, to build a 4-color compact *print-bar*

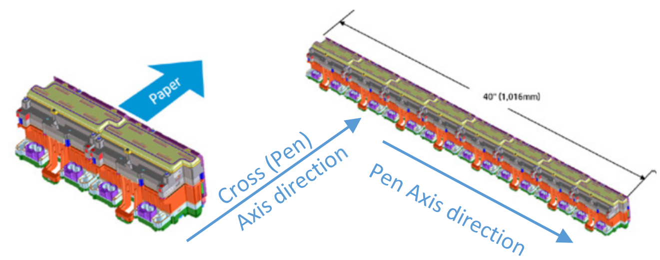

FIGURE 2
To obtain consistent image quality at one pass printing, the position tolerances of dies must be calibrated (called **print-head alignment**), both in the Pen Axis (PA) direction and in the Paper Axis or Cross-pen Axis (CA) direction (shown in figure 2). Since the 4 colors are laid in the same silicon chip the tolerances in position between them are small enough so no color-to-color alignment is needed.
On the other hand, tolerances in drop weight might lead to color differences and inaccuracies between dies, so a **color uniformity calibration** is needed.

Figure 3 and Figure 4 show the importance of these calibrations in PWA in 2 typical image cases. When printing technical drawings with an uncalibrated printer the effects of Cross Axis direction print-head misalignment can very visible as broken lines.

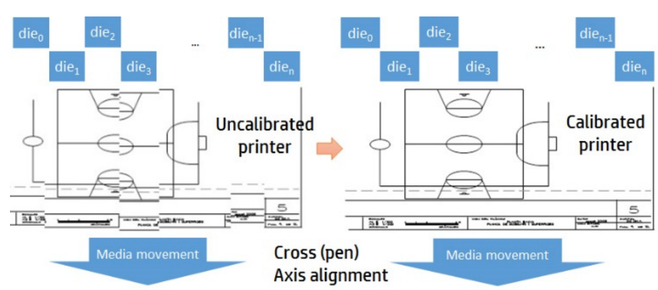

FIGURE 3
In images with solid area fills with an uncalibrated printer the color differences and misalignment in PA direction appear very visible as darker/lighter bands (between dies and in the junction of them) as it can be seen in Figure 4.

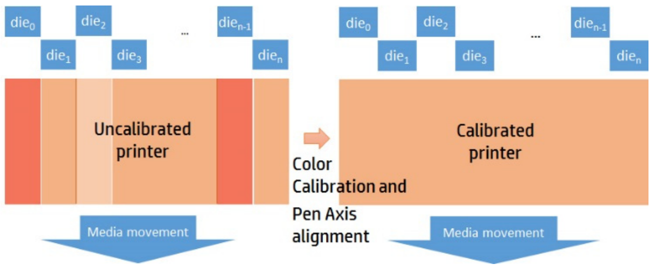

FIGURE 4

Both calibrations are triggered in the initial printer installation or in case of print-head replacement, but also in the case of printing in a wider media that the used in previous calibrations. Since only the dies able to print can be calibrated, that is, the ones falling inside media width, the calibration of the complete print-bar is not always possible.

The article covers first innovations in print-head alignment. In second place, the color uniformity calibration and colorimetric strategy for LF PWA are presented. Finally the innovations introduced to deal with the incompleteness of calibrations when the media used to calibrate does not cover all print elements are explained, which apply to both position and color calibrations.

Print-head alignment

Challenges in Large Format Page Wide architecture

Compared to scanning printer architectures, the requirements for print-head alignment in PWA printing represent a challenge in two independent areas; a challenge in accuracy and a challenge in robustness to sensor trajectory.
On one side, the dot placement accuracy in 1-pass printing needed is very high, since multiple passes modes that can mitigate the effects of misalignment are not available. Furthermore, to cover a large format media (for example, 40 inch in HP Page Wide XL 4/8000), such accuracy is needed consistently in multiple instances of die alignment (47 in the given example).
On the other side, being an auxiliary subsystem not used in printing, the carriage subsystem that includes the calibration sensors has further cost and functionality restrictions in PWA, so that the trajectory of sensors relative to the calibration patterns is less accurate than in scanning printers.

In addition to these two big challenges, the error range that print-head alignment has to cover in the inter-modules will be bigger. This is because the print-bar is obtained by stacking print-head modules, While error tolerances between dies inside a module are of the order of a few pixels at printing resolution, the inter-module case can grow up to the order of 10-20 pixels.

Print-head alignment strategy

With typical strategies and patterns of print-head alignment for scanning platform, the requirements of 1) high precision, 2) robustness to trajectory error, and 3) wide error range, are difficult to meet with a limited calibration time and media usage.
The solution is possible if the calibration is divided in 2 separated parts, each of one focused in different goals:

1. Coarse Alignment: a fast and compact pattern that can measure a wide error range.
2. Fine Alignment: Interferential patterns that provide the desired precision.

In the following sections both parts of the alignment are detailed, in particular showing how the patterns have been made robust to trajectory errors.

Sensor trajectory errors and alignment patterns

The calibrations sensor spot trajectory cannot be expected to follow very tight straightness tolerances, since the sensor is housed in an auxiliary carriage with many cost restrictions.
To illustrate the effects on alignment patterns analysis, general trajectory errors will be shown as local skew.
In Figure 5 and Figure 6 it is shown how N shape patterns are used to determine CA alignment, but are affected by sensor trajectory errors.

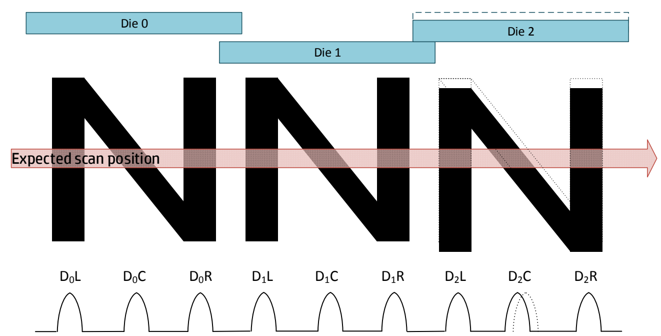

FIGURE 5

This pattern, and other block based patterns which are very common in scanning printer alignment procedures, work by measuring the actual **position** of the different parts or block of the pattern (3 "legs" for the patterns in the example of Figure 5) and compare it with the theoretical position of these blocks. From the differences of the measured vs. the theoretical positions one can determine the errors in position of the printing die.
This is illustrated in Figure 5, in the bottom of which there is the signal obtained by scanning the printed patterns by a densitometer.
As die 2 is below its nominal position, left the peak from center leg D_2C is shifted to the left. From the differences of distances between peak maximums (D_2C - D_2L) minus (D_2R- D_2C) the actual CA error can be measured.
When using this block or position based patterns, skew in the scan biases the measurement of the die alignment, as shown in dotted scan portions in Figure 6.

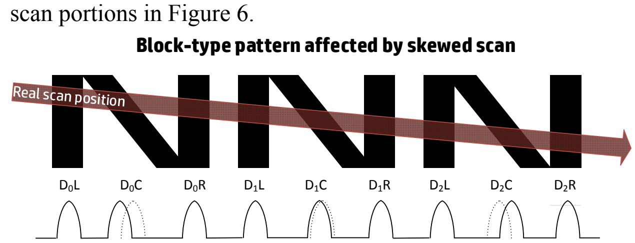

FIGURE 6

In contraposition, interferential or vernier pattern [1] works by overlapping a reference part printed with the edge of one die (parallel lines) with an interference part (lines that in each region increment offset in one unit) printed with the edged of the adjacent

die. As shown in Figure 7 when CA relative error is 0 (die1-die0) the overlap region with less optical density (OD) corresponds to the center (no offset in interference), but when the error is +1 as in die2-die1, the overlap region with less OD moves up one position.
The measures of the pattern are obtained by scanning over the different regions along the print-bar and finding the lightest region for every adjacent die overlap.

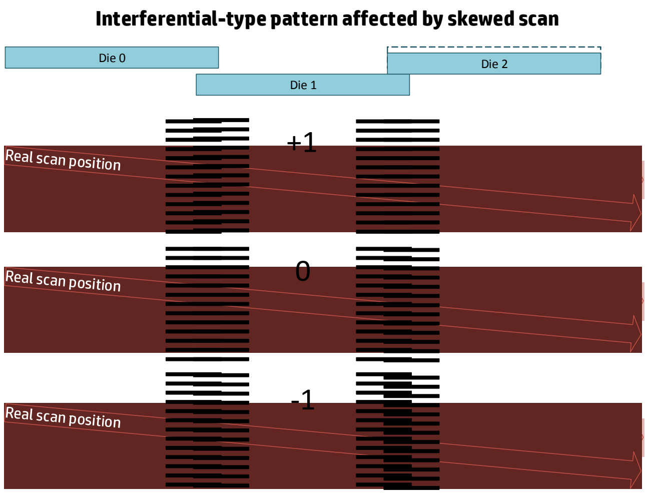

FIGURE 7

These patterns are robust to scanning trajectory errors by construction, since the height of the regions for each tested error is chosen to cover the trajectory range. Interference patterns are used in 2nd part of the alignment (Fine alignment) and, as detailed below, give very precise results but require a substantial amount of space and number of scans.

Coarse alignment

A new invention [2] in the form of a hybrid pattern between block and interference types, provides a wide range and robust pattern in very compact form.

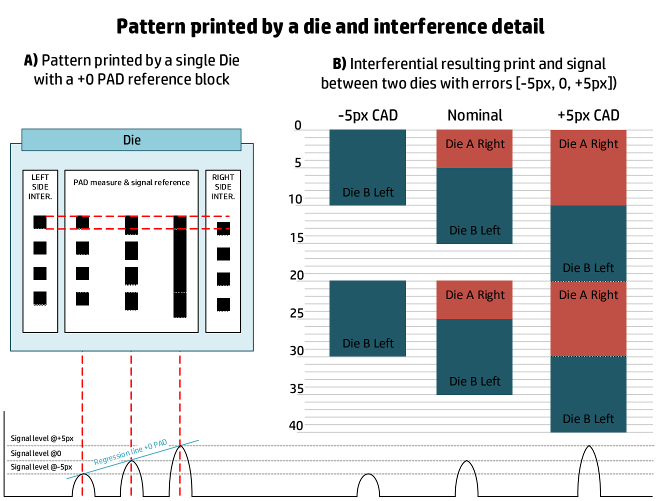

FIGURE 8

As shown in Figure 8A, each die prints 3 references with center nozzles than don't overlap with other dies, and staggered blocks at each edge of the die that will overlap with adjacent's.
Note that right side edge blocks are staggered half height with respect the left side edge blocks. When the blocks in one edge interfere with the adjacent die ones, as illustrated in the 3 cases of Figure 8B, the staggering causes that the bigger the CA error (in positive sign), the lesser blank space will have the resulting vertical block, and the higher the corresponding peak in the scanned signal.
In Figure 9 it can be seen, for example, how Die2 vs. Die1 error generates a higher interference peak than Die1-Die0 interference.

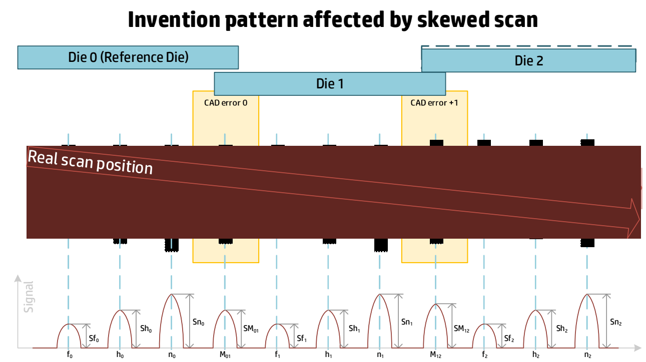

FIGURE 9

The magnitude of the error will be calculated by comparing the height of the interference peaks SM_{0i} with the height of the references Sf_i, Sh_i, Sn_i (which simulate known errors).
Since the block pattern is repeated along CA axis, the resulting concept is also robust to scanning trajectory errors.
Also note that the error in Pen Axis direction can be determined for each die. This is done by comparing the actual peak position of the 3 references f_i, h_i, n_i with respect to their nominal positions. So, further saving of calibration time is achieved: a single pattern and a single scan can be used to measure the errors in the 2 directions.

Fine alignment

Once the error (with initial big range) is determined by coarse alignment (with an accuracy of +/- 2 pixels typically), the high precision result needed for 1 pass Image Quality can be obtained by using the more extensive but accurate interferential patterns, that only have to cover the +/- 3 pixel range once the results of the coarse alignment have been applied.

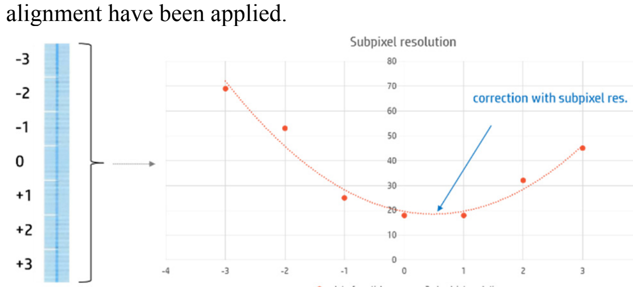

FIGURE 10

As shown in Figure 10 the sub-pixel reading can be obtained by interpolating a 2nd order function to the 1 pixel step block readings, and finding the fitted function minimum.

In addition, in the case of PA, robustness to failing nozzles is achieved by adding a small internal staircase to each of the blocks, so that the pattern is generated using all the nozzles (not only a few of them as in the case of straight parallel lines) and the effect of one or more nozzles being clogged or dead is very negligible. See the detail of this pattern modification in Figure 11.

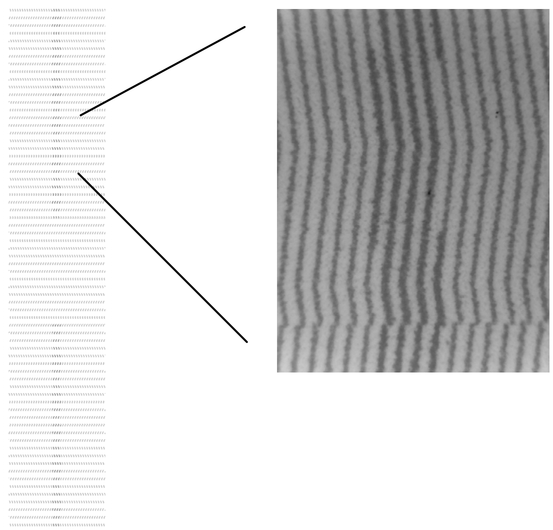

FIGURE 11

Color Calibration

Color calibration consists of a procedure triggered by the user or by operations such as a print-head replacement as explained above, whose objective is to ensure color uniformity across the print-bar, as depicted above in Figure 4.

As shown in Figure 12, the color calibration procedure starts by printing a diagnostic image color squares at different shades, then measures them with the aim of characterizing the individual behavior of each die. Then, a single reference or a 'target' for the whole printer is defined, in the sense that all dies will resemble that reference after calibration. Finally, an algorithm uses the individual die characterization plus the reference to create a set of 'Compensation Values' that describe the correction (in terms of drops/area) required for that die to print as the reference.

Once calibration is completed, any subsequent user printing operation will include the extra step of a 'Drops/area compensation function' D_i which, for each individual die i, performs a correction so that that it resembles the reference in colorimetric terms. Note that such compensation is applied in CMYK space, and that the RGB → CMYK color separation needs to be run beforehand. After the drops-per-area compensation Di, flow continues as usual through the Halftone and Print-head driving stages (among other operations), denoted as H_i.

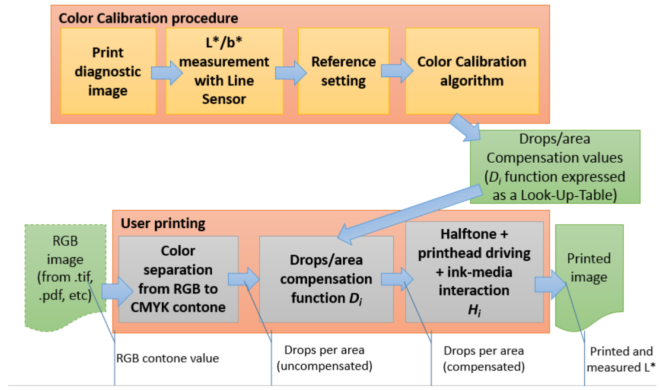

FIGURE 12

Color procedure in detail

The data flow stages are described hereafter in more detail (see Figure 13). A diagnostic image is printed at the beginning of the Color Calibration. It consists of six different shades of one of the primary colors, printed at the drops-per-area defined in table t. The shades are scanned with a densitometer. Non-inked areas are scanned as well, in order to perform a background-based signal compensation that minimizes the disturbances in the signal due to media shape and other noise [3] (see Figure 14). The process is repeated for each primary color (CMYK). Then, sensor signal is transformed to the L* (lightness) domain.

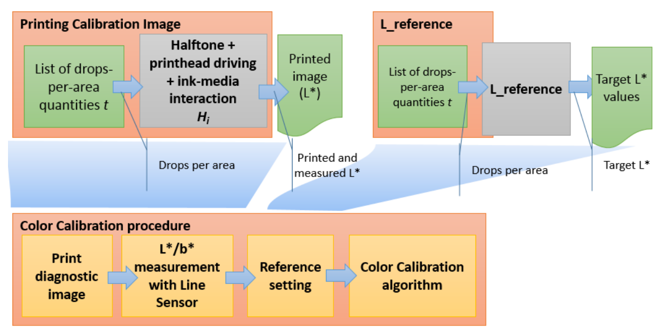

FIGURE 13

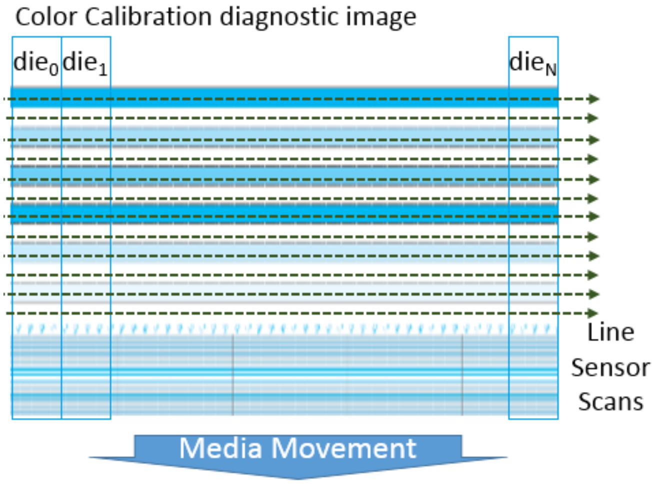

FIGURE 14

The result of such measurements is a detailed characterization of the function H_i, which encompasses the processes of halftone, print-head driving and ink-media interaction (see Figure 13Figure 14 and Figure 15). In other words, H_i maps drops-per-area to L* for each die. H_i is a die constant and does not change along time:

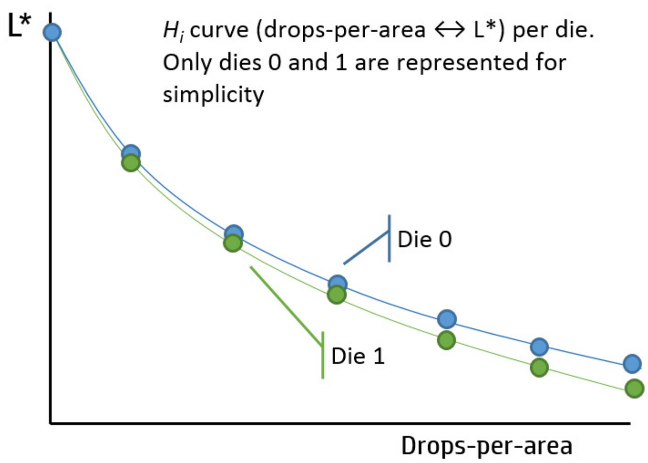

FIGURE 15

The next step is to determine a common target *L_reference* that all dies can achieve. The point is that if all dies resemble the same common reference, then they will be equal between them.

Setting a common target or reference is not a trivial task. Many options are possible and each one comes with a set of advantages and tradeoffs. PageWide XL series printers choose their references according to a patented algorithm [4] that enables the calibration values to be exported to other media later on. In subsequent explanations, it is assumed that a target function *L_reference* has been defined, whose input is a table of drops-per-area values and its output is the corresponding objective L* that all dies need to achieve.

To summarize, at this point the following data is available:

From the print & measure process:

$$L_i^* = H_i(t) \qquad \text{[per die]}$$

Calibration reference:

$$L\_reference\,(t)$$

The objective is to find a drops-per-area compensation function D_i which, when composed with H_i, results into the *L_reference*:

$$L\_reference = H_i \circ D_i(t)$$

Isolating:

$$D_i(t) = H_i^{-1} \circ L\_reference$$

The computation of $D_i(t)$ is beyond the scope of this article, and it involves the usage of interpolation techniques to invert function H_i. Result D_i is usually expressed as a Look-up-Table, and this table is referred hereafter as the set of *Compensation Values*. They essentially describe the drops-per-area corrections that each die requires to print to the same colorimetry as their neighbors. Such values are stored in the printer controller, and will be used in any subsequent user plot to obtain a uniform output.

PageWide XL series printers run the color calibration on a single media (usually Polypropylene, whose mechanical properties are stable), then initiate an export process for which 'Compensation Values' are properly generated for the rest of the media set. The export process preserves properties such as their ink cutoff and output linearity.

Changes in media edge and width

One problem to overcome is that the position of the printing substrate with relation to the dies may not be constant along time. For that, there may be printing elements that start to participate (or cease to participate) in the printing operation depending on the position of the substrate. As both Print-head Alignment and Color Calibration are only able to calibrate those print elements that participate in the printing, if printing substrate moves and other printing elements start to participate, those print elements will be uncalibrated. Figure below shows a printer that was calibrated under situation A then moves to situation B where a non-calibrated printing element starts to participate.

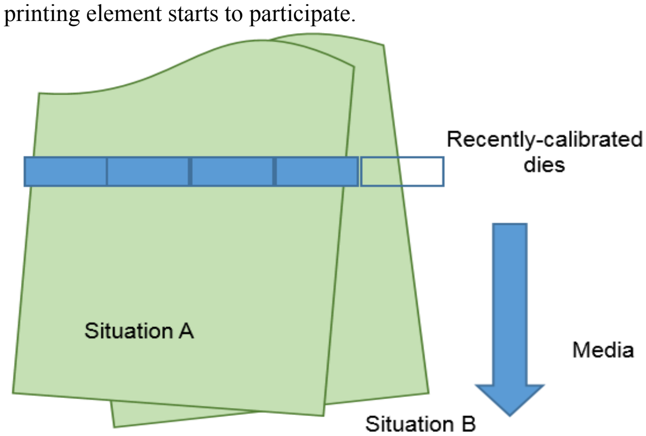

FIGURE 16

Such changes may be due to different media types moving in slightly different directions, or the mechanical tolerances between the different drawers in a multiroll printer.

A solution is implemented for which the printer controller keeps a record of the *relative* last-known-good (LKG) calibration coefficient ratios of each die versus its neighbor. If a die needs to print but it has not been calibrated in the last Print-head Alignment or Color Calibration, then its calibration values are inferred from the LKG ratio set [5].

The simplified process is depicted in Figure 17.

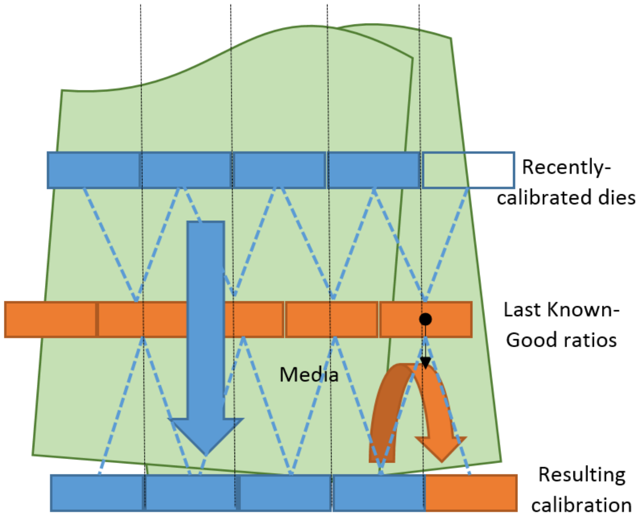

FIGURE 17

The use of historical data is a very effective solution when combined with an initial calibration (during the printer installation by the reseller at customer premises, for example) using the maximum accepted media width. This way the historical set contains data for all print elements, and can be used in subsequent operations.

Acknowledgements

A significant part of the large format PWA print-head alignment is leveraged from HP Officejet Pro series development. We want to thank to Hsue-Yang Liu and the Vancouver HP team for the insights and helpful conversations.

References

[1] Jean F Plante et al., 'Calibration method for a printer', US Patent 7,380,898 B2 (2008)

[2] Patent pending.

[3] Pau Soler et al., 'Compensating for drift and sensor proximity in a scanning sensor, in color calibrating incremental printers' US Patent 7,023,581 B2 (2006)

[4] Patent pending.

[5] Patent pending.

Author Biography

__Martí Rius__ received his BSc in Physics from Universidad Autònoma de Barcelona in 1995 and his MSc in Electronic Engineering from Universitat de Barcelona (Spain) in 1998. After a one-year internship at CSEM (Neuchatel, Switzerland) working on sensor development, he started in 1999 as an ASIC design engineer at Large Format Division in Hewlett-Packard Barcelona (Spain). He held that position for 5 years. Afterwards he became a WS engineer and was engaged in the development of Aqueous and Latex ink products aimed at Graphical markets. He has lately worked on new technology development in the context of Page Wide Printing and Color Uniformity Calibration methods.

__Marc Casaldàliga__ received his BSc in Physics from the "Universitat Autònoma de Barcelona" (1997) and the MSc in Computational Physics in "Institut de Fisica d'Altes Energies" (Barcelona, 1999). He joined then the MAGIC Telescope Collaboration, which develops and runs a gamma ray Telescope in the Canary Islands, Spain.
Since 2002 he has worked in R&D division in HP Large Format Printers in Barcelona. From the beginning he has been involved in the investigation and development of HP Optical Media Sensor. He worked in the writing system development on HP LX series printers and more recently in the XL Page Wide printers.