PRINT DIAGNOSTICS IN PRINT CONTROL

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ABSTRACT

A top-down approach to diagnostics in the computer numerical control (CNC) of printing has been presented. First, the means and objectives of CNC are outlined, and the ensuing requirements to print diagnostics have been found. Then the subordinate to CNC features of print diagnostics are discussed. And finally, the system structures, of both hardware and software, have been designed.

1. Print Control: Means and Objectives

The print control system should use a color bar and a scanner for controlling both color and register. The Harris Color Bar (HCB) has six bands of four solid color (black, magenta, cyan, yellow) fields, three eight-field register bands and two eight-field diagnostic bands, per half-web (17-19 inch ribbon). The diagnostic fields include slur patterns for all colors, overprint trapping, and gray-scale patterns.

As usual, the HCB is mapped by distribution of ink actuators across the ink fountains: here we have a color patch per each pair of ink keys which is a little redundant with respect to the spatial frequency response of the inker [1,2], but this takes care, at least partially, of non-linear effects of color control.

The register fields have special patterns allowing to evaluate misregister while scanning the color bar. They reduce the task of register evaluation to the color intensity evaluation problem. We do not consider this problem here, because it is beyond the scope of the paper.

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Objective of print control, as usual, is to assure that the press produces signatures with narrow, predetermined tolerances with respect to the proof, the reference color bar, and does it in the most efficient way [1]. Such a computer numerical control (CNC) of printing can be achieved only if the feedback transform, the color bar and the scanner, accurately present the press variables, i.e. the system satisfies the observability requirements [3].

Conversely, the situation can be taken as such: We have a feedback signal, let's detect whether this signal is controllable or not, i.e. is it an output of the controllable ("signal") or of the uncontrollable ("noise") variables.

Thus, considering the controllable variables of printing as a signal, we can assume that everything else - print defects, color bar defects, scanner failures and errors - are a noise that should be detected and separated from the signal in order to assure a satisfactory control.

2. Print Control: Noises and Tolerances

Figure 1 presents 3 randomly chosen sets of some color fields for 30 consecutive signatures. It can be seen that the readings vary in a range of 0.1 units of optical density (OD) and are practically uniformly distributed. The same variation has been reported by other researchers [4].

Accordingly, the r.m.s. value of this dynamic stationary printing noise [5]*:

$$\sigma_d = \sqrt{\frac{1}{0.1}\int_{-0.05}^{0.05} x^2\,dx} = 0.0289 \cong 0.03 \text{ units of O.D.} \qquad (1)$$

This σ_d is good news: for the usual screen values $a < 0.7$, the noise is $\sigma_a < 0.02$, less than human eye can discern.

*The r.m.s. values of noise calculated directly from the series in Figure 1 are $\sigma_k = 0.032$, $\sigma_c = 0.023$, $\sigma_m = 0.025$, respectively for the black, cyan and magenta series.

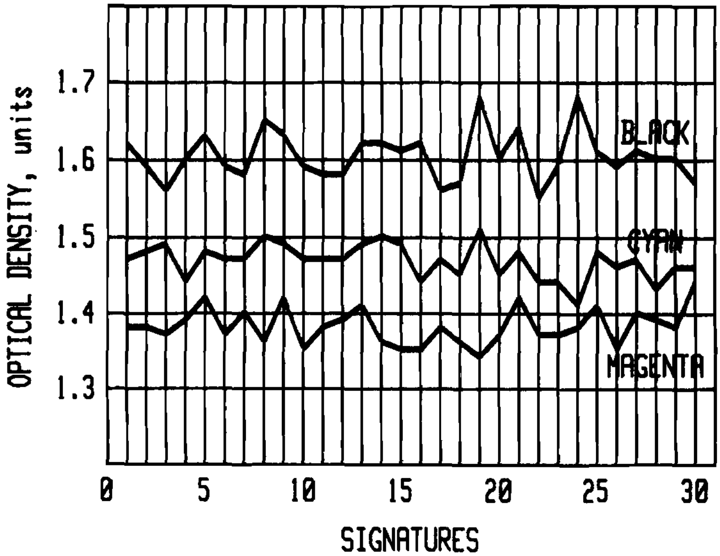

FIGURE (1) Print Noise: Optical density variation from consecutive signatures

Using the criterion of negligible error [6], for the negligible deviation of 5% in the signal, we can find a condition of reliable control: the signal S should be:

$$S_{0.05} > 0.03/\sqrt{1.05^2 - 1} = 0.094$$

$$\cong 0.1 \text{ units of O.D.} \qquad (2)$$

For a 15% negligibility level, $S_{0.15} > 0.053$. Thus a difference reading of 0.05 units of OD can be expected to be moderately corrupted with noise, and a reading of more than 0.1 can be expected to be "clean", with negligible influence of noise.

The value (2) of reliably controlled signal can be interpreted also in another way: because there are many sources of disturbances, we can expect the overall noise distribution to become (according to the central limit theorem of probability [5]) the normal distribution with $\sigma=\sigma_d$ (1). Then, with the probability less than 0.3% we can expect the combined disturbance to reach the signal level of

$$S_{0.05} = 3\sigma_d \cong 0.1 \text{ units of O.D.} \qquad (3)$$

Therefore, it is practically improbable for a disturbance to reach the signal level of $3\sigma_d$.

This unconditional noise level determines also the accuracy of devices: The maximal allowable error of scanning the color bar may be equal to $\sigma_d = 0.03$, and it does not make sense to ask for its higher accuracy.

Now, assume that we have hickeys with a level more than 0.2 (Figure 2). By contrast, this noise can be called "static" (it exists and can be detected at any given signature) and "non-stationary" (it can appear and later disappear). It can be seen that it does not make sense to correct the density by 0.15 in this case - it is more reasonable to wash up the blanket. But, if the hickey disturbance is small, say 0.1, we can compensate its influence with increased density.

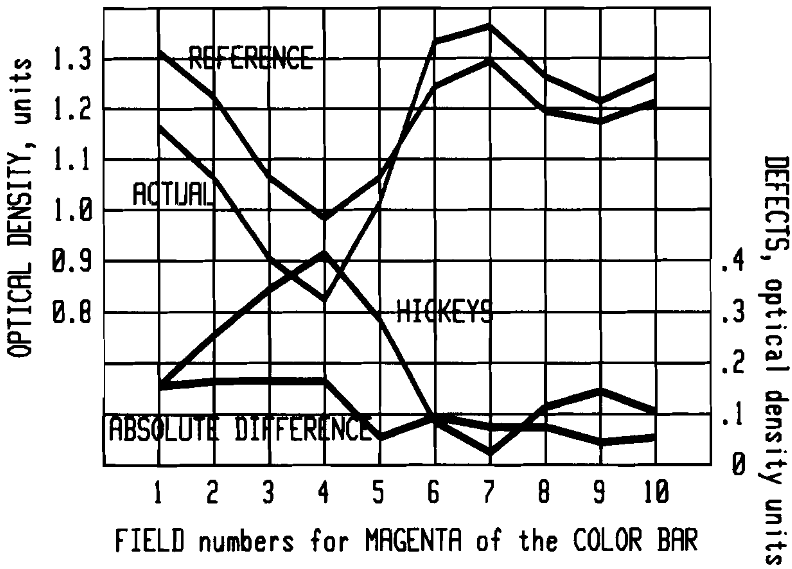

FIGURE (2) Print Noise: Signal is lost in noise of hickeys.

Thus, we come up with such a system of tolerances for color control:

- Less than 0.05 is an insignificant level, no control is allowed/needed.

- 0.05 - 0.1 is the margin of significance for color control.
- Less than 0.15 is insignificant level for static diagnosed noise; it may be compensated with control.
- 0.15 - 0.2 is the margin of significance for diagnostics.
- Greater than 0.2 is the noise level reported to pressman , but the ink control is still allowed.
- Greater than 0.3 is the emergency noise level , no ink control is allowed .

The conditional static noise brings about a critical task to the print control: determine whether the control should be applied at all. Therefore, detection and evaluation of this noise carried out by the print diagnostic system becomes an inseparable part of print control.

3. Print Diagnostics: Subject and Means

Traditionally, the subject of print diagnostics [7,8] is to detect and evaluate parameters, such as slur, dot gain, trapping, grey balance, etc. that could assist a pressman in his "control by appearance". But these parameters, while being available from the HCB, are of little help to the computer numerical control.

In automatic control, the subject is different. The main task of diagnostics is to detect whether the feedback signal read with the scanner is corrupted with noise and to evaluate this noise - in order to decide what to do with this signal: to control or not to control.

The essence of color control is simple: we increase or decrease the ink flow in order to make the printed color denser or lighter. Therefore to provide a proper feedback for this control, we have to print solid fields on the color bar, and the optical densities of those fields read by the scanner will represent the ink flow.

On the other hand, practically all print defects - scumming, tinting, hickeys, picked-up paper (picking), mix of inks, particles of dirt, ink slinging and emulsification, etc. - cause non-uniformity, unevenness of those solid fields.

In other words, all print defects are "screening" the HCB fields, and if we use halftone (screened) diagnostic patterns, the screen defects (slur, dot gain, etc.) that should not influence print control become indistinguishable from print defects. This is why a solid is such an important diagnostic pattern.

Therefore, the ideal pattern for color feedback control, with a great potential for detecting print defects, is a solid. This is the main means for print diagnostics.

As far as the sensors are concerned, it is obvious that diagnostics calls for reading of every production ink color patch not only with its complementary filter, but with others as well - in order to detect mix of inks, picked-up paper, etc. In essence, diagnostics calls for using a set of sensors, for switching from densitometry to spectrophotometry.

We should also distinguish these kinds of unevenness - the micro- and the macro-. Broken fields, large hickeys, slinging are some examples of the macro-non-uniformities (Figure 3a), as distinguished from the micro-non-uniformities presented by Figure 3b. These defects should be detected by finding the range of several readings per field (Figure 3c). In Figure 4 is given an

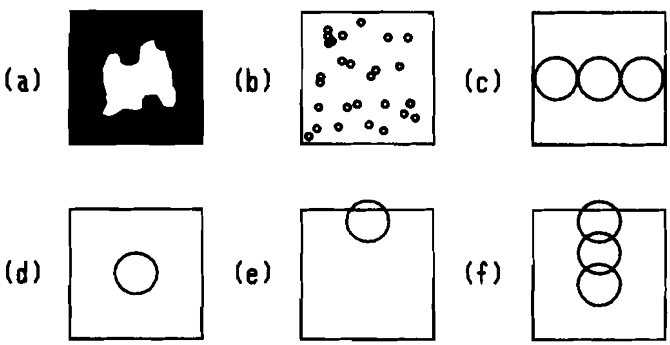

FIGURE (3) Print Diagnostics: Case studies for the solid fields example of such a range, and it is clear that field #8 for black and field #6 for cyan present unevennesses. Indeed, observation of those fields has shown that large disturbance in the black patch exists and some tinting was evident for the cyan patch. For the black patch the disturbance was a large hickey.

On the other hand, ranges for all the other fields are less than 0.1 OD, and present usual printing noise.

The readings should be staggered not only across the web, but also along the web - across the color bar. Indeed, we assume that the readings are "right": the aperture of the illuminated color spot is in the center of the field (Figure 3d). But, what will happen if, for whatever reason (misalignment of the scanning, late trigger, defective print, etc.) the reading is on the border of the field (Figure 3e)?

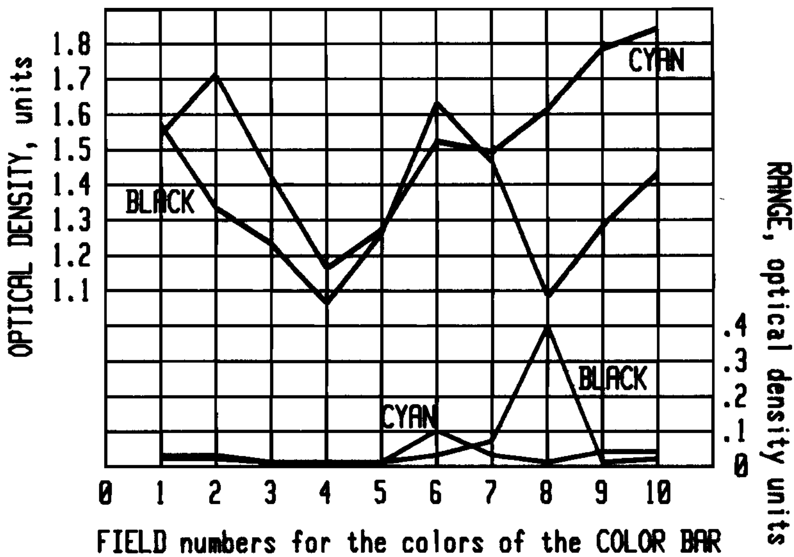

FIGURE (4) Macro-non-uniformity of a field:
Range values with respect to optical density

This situation presents a very serious problem, because there is no way to find out from the reading as such that it is wrong. The only way is to take slightly staggered readings (Figure 3f) and compare the readings: if the difference is within the printing noise margin, the reading is reliable. Needless to say that is not a simple task.

The staggered sensors should be equal or close spectrally, and calibrated to the same color patch in the reference color bar. This is to assure the sensor differences will not be taken as alignment differences. The alignment check has to compare readings of all the patches along the color bar, since the first patches that are read may be aligned, but the rest may be not. This condition may happen by skewing the color bar with respect to the scanner sensors.

In order to obtain necessary signal resolution, the sensors should have both linear (intensity) and logarithmic (density) output channels. The linear channels have better sensitivity (resolution) to high light levels (i.e. reflected light which approaches light levels reflected from white). Thus the linear channels provide better resolution for measuring screen patches for area coverage.

The logarithmic channels have better sensitivity to low light levels. Thus, as usual in printing, the logarithmic channels are used to obtain values from solid patches. The use of linear and logarithmic output channels does not only provide better sensitivity at respective light levels, but also reduces the computational time requirements of the computer. For example, a color bar with 100 fields, read by a scanner with 3 sensors, reading each patch 3 times, there would have to be 900 logarithmic computations. If the time for one computation is 1 millisecond then there would be almost one second wasted on the conversion, instead of computing control algorithms.

A system of reference color bars is another important means to provide an accurate print control. First, there should be a reference bar (sometimes called a calibration strip) that is scanned each time the off-press scanner is used. This reference provides a means of referencing two different scanners. In other words, a reference color bar read by a printing house's "standard" densitometer, may be continuously scanned along with printed color bars to relate the printed color bars' density values as read by the scanner to density values as would be read by the "standard" densitometer. This reference color bar also provides calibration of sensors to read proper density/intensity values and calibration of sensors to each other for alignment and diagnostic purposes.

Secondly, there should be a "print" reference color bar. This reference color bar is a pressman approved (for color and register) signature. This "print" reference bar should be from the "office copy" signatures.

This color bar then becomes the target for the print control system to reproduce on the press.

Thirdly, there needs to be a reference color bar for an on-press scanner. This can be achieved by whatever signature the on-press scanner reads, that signature is then read by the off-press scanner. In this way the on-press scanner is referenced to the off-press scanner, and thus the on-press scanner can be calibrated. This procedure is very similar to that of the "calibration strip" reference bar read by the scanner and a "standard" densitometer.

Thus, in order to provide reliable print control, every field of the color bar should be read by a set of sensors; every sensor should read the same field several times; equal or spectrally-close sensors should be shifted with respect to each other; every sensor should have both logarithmic and linear output; and at every scan every sensor should scan a reference color bar with known values of ODs.

The brief discussion above shows that the system of print diagnostics should consist, in reality, of the 2 parts with different tasks:

- the PRINT diagnostics itself which presents objective defects of printing irrecoverable by the control system;
- the SCAN diagnostics which presents defects of scanning (misalignment of the color bar, wrong its positioning, etc.) and/or control system, partially or fully recoverable by operator.

4. Print Diagnostics: Methods and Parameters

The basic expedient of print diagnostics is to use multiple readings of a color patch, both spatially and spectrally.

While reading the color patch spatially, the optical density range in both directions, i.e. macro-non-uniformity and misalignment, of the patch is acquired. The range is calculated from several contiguous readings which are also averaged to obtain the density value of the patch. The absolute values of the differences of the readings are added up and are then divided by two:

$$RANGE = \left(|a_1 - a_n| + \sum_{i=2}^{n} |a_i - a_{i-1}| \right)/2 \qquad (4)$$

a_x is the x^{th} reading.

n is the number of readings taken.

This RANGE value obtains in a straightforward way the value of the difference between the largest and smallest reading of the patch. Equation 4 is equivalent to the following:

$$RANGE = MAX(a_1, a_2, \ldots a_n) - MIN(a_1, a_2, \ldots a_n) \qquad (5)$$

While reading the color patch spectrally, the values representative of hickeys, picking, dirt and mixture of ink are obtained. Hickeys and picking values are obtained from the analysis of the "dark" part of the color's spectrum, (e.g. the green wavelengths for magenta ink). Dirt and mixture of ink are obtained from the analysis of the "light" part of the color's spectrum (e.g. the blue and red wavelengths for magenta ink).

Most of the analyses using the spectral approach check the properties of additivity and proportionality failure of densities [9]. This is necessary, though insufficient in diagnostics.

The "light" parts of a color's spectrum are the areas most sensitive to addition of dirt (black) or different colors into the patch. Therefore, by comparing sensor readings in different "light" parts of the spectrum, dirt and mixtures of ink can be detected and discerned. Generally, if the readings differ from the reference by equal amounts, dirt is present; and if the readings with respect to the reference differ from each other by more than a threshold value, a mixture of colors is present.

The "dark" parts of a color's spectrum are the areas most sensitive to hickeys' and picking non-uniformities. Just as for dirt and mixture of ink, hickeys and picking can be detected and discerned by comparing sensor readings in the "dark" parts, instead of the "light" parts of the spectrum. Hickey defects tend to make different sensor readings to vary by equal amounts, as it was the case with dirt. Picking, because it can be a different color of paper on the solid patch, is recognized by the sensor readings differing by more than a threshold value.

All these techniques are used to find in a quantitative way the optical density deviation due to defects on a solid patch. The basic measurement parameter thus chosen is optical density. The optical density value

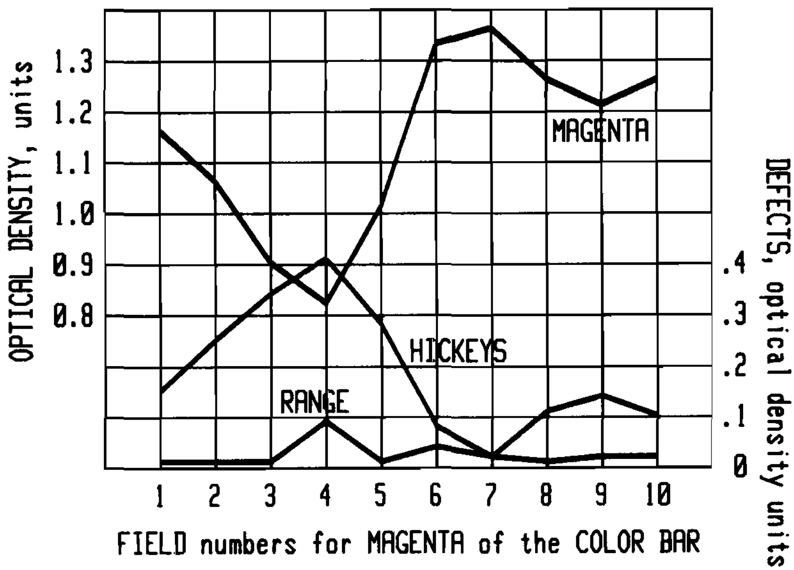

FIGURE (5) Print Diagnostics: Large hickey detected as a combination of RANGE and HICKEYS will provide the density value error with respect to what an ideal solid color patch density would be. This parameter is important for CNC, in order to provide not only good control of color but correct control.

Figure 5 presents an example of what was just discussed. The top curve illustrates the large variation of optical density that can exist across a single web. The curve labeled RANGE shows the macro-non-uniformities of the magenta solid patches across the web. At field #4, there is a large disturbance. The HICKEYS curve gives a measure of hickeys (large or small) in a patch. Progressively in fields #1, 2 and 3 small hickeys were present, and the curve represents that. At field #4, the HICKEYS curve also recognizes the large hickey, along with the smaller hickeys in the field.

5. Print Diagnostics: System Approach

Requirements of print diagnostics introduce rather definite design decisions both to hardware and to software of the print control system.

Hardware-wise, the print control structure is simple and straightforward. You need 4 parts in it:

- Press Interface computer (PIC) which has a set of output channels for controlling the actuators and a set of input channels for feedback of actuator positions;
- Controller computer which processes the scan feedback data, transforms them into the control data, and sends them to PIC;
- Scanner which scans the color bar and sends the scan data to the Controller;
- Control console from which the pressman observes the results of operation and sends commands to the control system.

All 4 parts are available on the market, and composing of them a system seems to be simple and only a matter of cost efficiency. From this point of view, the only special-purpose device is the Scanner, but we have a lot to chose from: all 3 possible versions of scanners

- off-press, single- or multi-eyed, single- or multi-sensor (Figure 6a [10,11]),

- on-press, single-eyed, multi-sensor (Figure 6b,[12]),
- on-press, multi-eyed, single-sensor (Figure 6c,[13]),

are available at least on the prototype level.

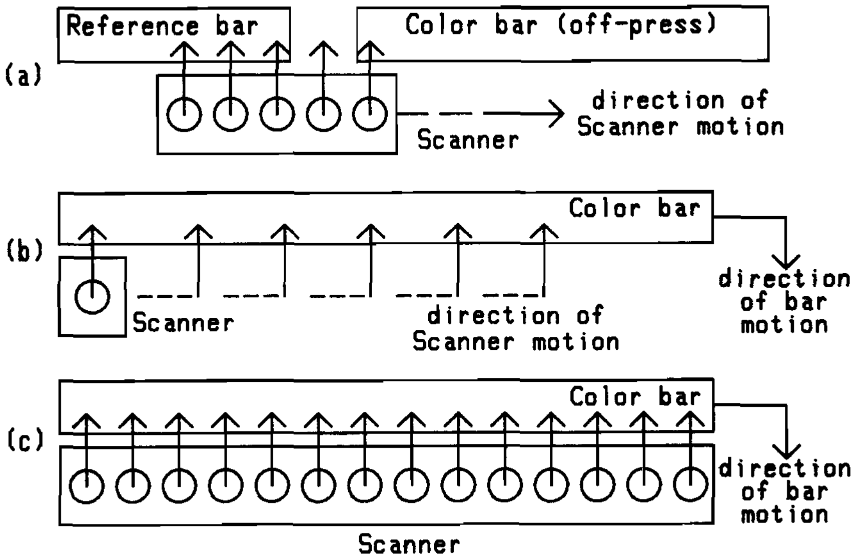

Figure (6) Scanner Configurations: The means of scanning color bars

Of course, preferable are the on-press scanners. They are more expensive, both in equipment and maintenance, but the promise of fully automatic operation is quite appealing.

The on-press scanners (Figure 6b,c) take readings while passing across the color bar (along the web). This is the major drawback from the diagnostic viewpoint, because *only one reading of a field per signature* is available, and there is no way to make sure that the readings are right (Figure 3d,e) - it is very difficult to take slightly staggered readings across the color bar (Figure 3f).

The multi-eyed scanner [13], because of its immobility, also cannot provide self-calibration by reading some known color patches with each eye, and it has a problem of reading every field through several filters. The single-eyed scanner [12], on the other hand, provides easily the self-calibration (by moving to some outside reference patches) and the multisensor readings, but it is slow and wasteful in data acquisition. Indeed, because it reads one field per signature passing, scanning of a 150-field color bar requires 150 signatures wasted, and at a speed 1200 FPM it will take approximately 15 sec (and at 300 FPM - 1 min!), more than an off-press scanner would take. If we want to take several readings per field, the time and waste found should be multiplied by the number of readings.

By contrast, the off-press scanner (Figure 6a), because it scans along the bar, perfectly meets the diagnostics requirements: there is no difficulty of taking as many readings per field as it is needed, with any set of sensors, staggered across the bar or not, scanning at every scan the reference color bar, etc.

Does it mean that the on-press scanners are doomed? Not at all. Simply the off-press scanner provides the necessary condition for feedback from print, and adding to it an on-press scanner will make it sufficient for the future real-time, fast, closed-loop controls of color and register.

Anyway, for an on-press scanner to function efficiently, you need to reference it with calibration and diagnostic data taken from time to time with the off-press scanner.

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