COLOR CONTROL BY IMAGE COLOR MEASUREMENT (A PROGRESS REPORT)

Robert P. Mason*

Abstract: In the two years since our first announcement of having achieved color control by direct image color measurement, we have learned that sheet-fed offset presses generally show random variations in color over a visually detectable range determined by process variables. Visually significant trends of change can be identified quickly and reliably using direct image color measurement and applying statistical process control methods. Indicated corrective actions are effective and, when performed in a timely manner, they provide superior color control to purely visual or densitometric methods. The records produced are suitable for certification of conformity to color uniformity requirements, and they provide the basis for statistical quality control analysis.

The tools are now available to establish standards for color uniformity within a run and for visually acceptable limits to differences between a sample and its target color.

Introduction

Two years ago at this forum[1], I introduced HunterLab's Process Image Color Control System (PICCS) for monitoring and controlling process image color. This operates by taking color measurements directly from selected image areas of

*Vice President, New Business Technologies, Hunter Associates Laboratory, Inc., Reston, Virginia.

a production run and deriving appropriate corrective actions from them where needed. The system:

- Uses direct image measurement.
- Measures a visually significant area (typically about 1" diameter).
- Produces data suitable for SPC.

Since that time, the system has been operated in a number of plants on hundreds of jobs over tens of thousands of samples. The evidence is firm, and the results are clear. The PICCS instrument system:

1. Provides a means for regular sampling of color during production runs.
2. Indicates timely corrections.
3. Provides a Statistical Process Control (SPC) basis for evaluating color performance in the run.

Background

Let me quickly review the techniques used in PICCS. Once image color has been brought close to that desired using conventional methods, the operation of the instrument system strongly parallels the actions of the press operator. He compares the image color of a new sheet with his color standard. He judges whether a significant color change has occurred and then deduces what he must do to correct it, if warranted.

With PICCS, the image color is measured and the corrections are indicated in terms of the influence that the inks being used have on the image color. It uses color-related properties of the production inks and paper on the job and synthesizes a mixture which will match the color of the agreed-upon standard image, whether it is a proof, an OK sheet, or an example of a previous job run. It computes the Equivalent Percent Ink

Coverage (EPIC) of each ink contributing to the color of the standard image. Measured samples are similarly characterized. Differences in EPIC between sample and standard are then reported in proportion to their effect on the image color as percent ink coverage errors. These corrections are derived only from color scale values determined from the measurements, and they side-step all possible reasons for the variations. There is no dependency needed on a model of the process in terms of dot gain, trapping, or the like, in this final color trim step.

The objectivity of the instrument removes the burden of judgment from the operator, the judgment of which inks need adjustment and how much, and allows him to apply his skill to determine the cause and corrective actions required. Figure 1 shows the elements of the PICCS instrument system described in the previous paper.[1]

Colorimetry vs. Densitometry

Many ask how colorimetric measurements differ from densitiometry and why the same information cannot be derived from readings with a densitometer. I will explain briefly.

The main differences are in the form of the numerical scale values presented for the intended purpose. Red, green and blue density color dimensions are selected to best indicate ink absorptions in the three separate parts of the visible spectrum used in the color separation process. The colors seen result from the visual response to the light reflected from the overlapping inks on various areas of the paper. The eye responds to that light in a very different way from the densitometer. Its response is modeled by three functions which have broad and overlapping bands called "the tristimulus functions."

Each system of scales is best used for its intended purpose. In PICCS, the three tristimulus functions are used because they represent how the customer's eye will interpret the reflected light in terms of color. An additional reason for using the tristimulus responses is that a system of color scales has been developed from them for convenience in communicating and specifying color and criteria for acceptability. These can be used in discussing color requirements with customers. The Munsell Color Solid represents a color order system using such scales.

No scales exist for conveniently interpreting density readings. The various GATF color diagrams do sort out some of the factors, but they do not portray color readings in a form easily interpreted throughout the range of all colors. They lack the underlying features of the color scales, that is, three psychologically independent dimensional coordinates with relatively uniform spacing over the entire gamut of visible colors.

The density scales are needed for allocating the building blocks from which the color is synthesized. The color scales are for evaluating the degree of achievement in reproducing a desired color. Since image color is what the customer sees and judges, we have designed a system in which perceived color is the common denominator for process image color control.

Process Characterization

In a coordinated test program, a series of production runs were measured, recorded and analyzed in detail to provide an understanding of the value of this method for characterizing the offset printing process. Three sheet-fed offset printed folding-carton manufacturers and one web-offset publications printer provided material and assistance in this effort.

EPIC values were determined from PICCS measurements for each of the three inks designated as the most significant contributors to the image color. The differences from standard were plotted for each sample measured throughout a run. Sample average and control limits for a sample size of four were computed and plotted with the graphs of the samples.

A considerable effort was made to record and display measured density values from these sheets in a form comparable to EPIC.

Where color bars were present, they consisted of solids not necessarily in line with any of the images measured. Density of color bars (DB) and density within image (DI) readings were taken after the samples were removed from the printing plant. For the density measurements, a commercially available densitometer was used. Uniform areas within the larger sampling area of the PICCS instrument were selected to assure that comparable measurements were made with the different instruments. Ten readings of the standard image were averaged to provide numerical standards for density. To permit a useful comparison, all density values were converted to percent dot area, using the Murray-Davies equations. A density of 1.00 was designated as 100% or solid; thus, a density of 1.30 became 106%. This scale was then comparable to the EPIC scale used in PICCS, and density differences from standard were plotted.

Comparisons of similar plots, generated from the same samples using the three measuring methods, were made; that is, the EPIC from PICCS, the Density in Image, and the Density of Color Bars nearby on the same sheet when available.

Review and comparison of these plots reveal a number of things about the effectiveness of PICCS and of the nature of the process. We found cases where the readings based on density agreed with PICCS, and a number of important cases where they did not agree. This was especially true where black or another dark ink was present. This is very important in view of the growing use of GCR, where black is one of three inks present. The examples shown are selected from the test series to illustrate typical findings of each point. Each is representative of many examples.

Figure 2 is an example of a run in which over seventy sheets were read using the girl's face as the measured area. The EPIC error for each ink, magenta, cyan and yellow, is shown for each measured sheet. The length of the bars are proportional to the error determined for each ink on each sheet. The samples are taken from the area around the step most visible in yellow. As you can see, the yellow was running below the target level and jumped up, then returned.

In Figure 3 control charts of averages and of ranges, using a sample size of 4, were prepared from the data in Figure 2. In addition, similar charts were prepared from RG&B density readings of the same images, and they are shown in the lower half. You will notice that there is a similarity in the shapes of the two sets of curves of the charts of averages. Both types of measurement are giving similar information. The computed control limits are placed symmetrically around the target value of zero for each ink. These clearly indicate where corrective action is needed to maintain target color within achievable limits.

These control charts reveal the expected characteristics - a random variation, typical of all processes, imposed on trends and on cyclic variations. Through the use of control charts, trends requiring compensating adjustments can be detected at early stages before an unacceptable product is generated. In general, this confirms the expected agreement between DI and EPIC, where chromatic process inks are used and comparisons are made with an OK sheet of the same run.

In Figure 4, measurements taken in density from nearby color bar solids are compared with the density of the image and with EPIC. As can be seen, at this color-trimming level of variation, there is little similarity between measured variation of the color bars and the measurements taken directly from the image.

Another example, shown in Figure 5, where the color bars were in line with the measured image area, the initial values taken from the printing run were very different from those of the standard. From these data, one quickly confirms what is widely known but not so clearly seen before, that solid color bars are an unreliable source of information about image color variation after the run is in progress.

You should also note here that there is much less parallelism between the upper curves of the corresponding inks. The three inks reported are the only ones present in the image - yellow, magenta, and brown. The densitometer cannot distinguish between changes in the brown component and the other inks, since the dark ink absorbs light at all wavelengths. This is where density within image measurements breaks down in an obvious way and gives unreliable reports of ink corrections needed.

Figure 6 is another illustration of this, shown in control charts for a run in which black is a significant component. In the chart of averages, the black clearly drops off over the duration of the run, as shown by both density and EPIC readings. However, the measurement methods disagree in reporting what happened to the magenta and yellow inks. The density measurements show a decline in all three, paralleling the black, and indicating the magenta and yellow were too low near the end of the run. The EPIC measurements show that the magenta and yellow were too high some of the time and within acceptable limits the rest of the time. A visual review of the samples confirmed the EPIC report. Here is clear evidence of the type of misleading information which could be derived from density readings within the image.

From this, we deduce the following:

Solid color bars are undependable in maintaining color within close tolerances during a run.

Except where an OK sheet from the same run is used as the color standard and only chromatic process inks are present, DI is also undependable.

The differences between the DI values and the corresponding EPIC values are attributed to the following factors:

a. The presence of more than one ink in the measured area prevents density readings from directly indicating single ink variations.

b. The different spectral responses used in reading the color and in reading density are significant where the standard for color is a proof or has been prepared with different materials.

c. The small size of the measurement area of the densitometer causes it to be more sensitive to positioning errors.

d. The difference in size between the measured areas of the two instruments can result in different curve shapes. Both are used for comparison of samples with standards taken from the same instrument though, and care was taken to select measured areas where this effect is at a minimum.

The PICCS instrument computes the EPIC of an ink based on its influence on the measured color. This avoids the problem of crosstalk and provides dependable guidance to the press operator on how to maintain target color. The standard can even be a proof made with a different ink set, as long as the apparent color is what is desired.

Conclusions

In summary, the evidence clearly supports the PICCS approach in which corrections are derived from sufficiently large-area sampling and measured color differences. Using PICCS, it is possible for the first time to characterize the printing process reliably in relation to its color uniformity.

After two years of extensive testing and use, we can conclude that direct image measurement is practical and meaningful in process image printing. A suitable analytical technique is used for sorting the effects of the inks, in regard to their actual influence on the image color, to prevent confusion from crosstalk between conventional separation channels.

This capability, for the first time, now allows true statistical process control to be exercised effectively by deduction of the proportional influence of inks in use on the image color actually produced.

Reference

1. TAGA Proceedings, 1985, "Specification and Control of Process Color Images by Direct Colorimetric Measurement," R. P. Mason, pp. 526-545.

PROCESS IMAGE COLOR CONTROL SYSTEM - PICCS 3000

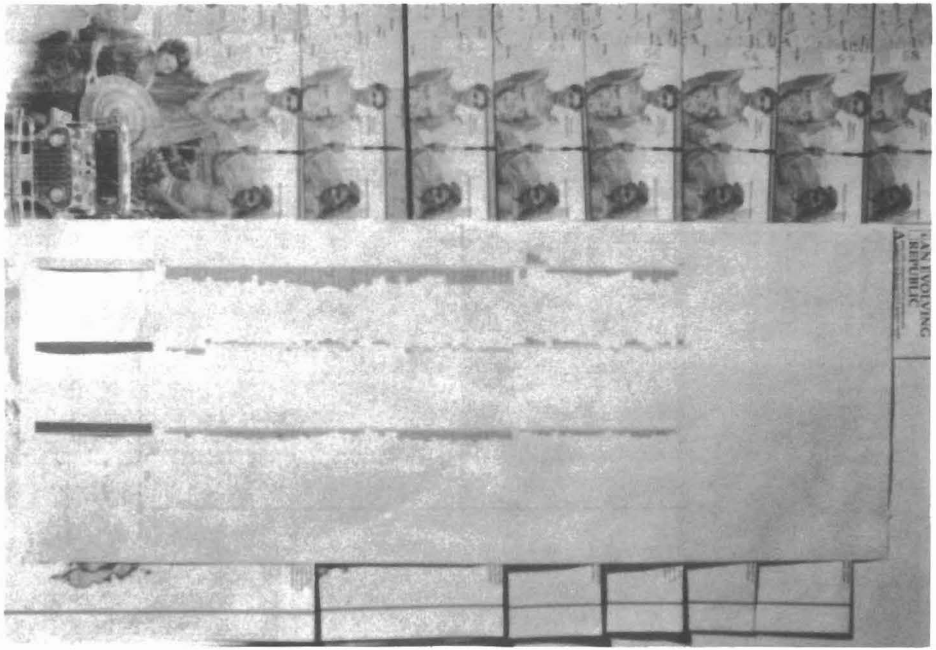
BY HUNTERLAB, INC.

FIGURE 1

YELLOW

CYAN

MAGENTA



RUN A

EXAMPLE OF GRAPHICALLY DISPLAYED EPIC DATA FROM A PRODUCTION RUN. SAMPLES SHOWN BRACKET STEP IN EPIC DIFFERENCES.

FIGURE 2

CONTROL
CHART OF
AVERAGES

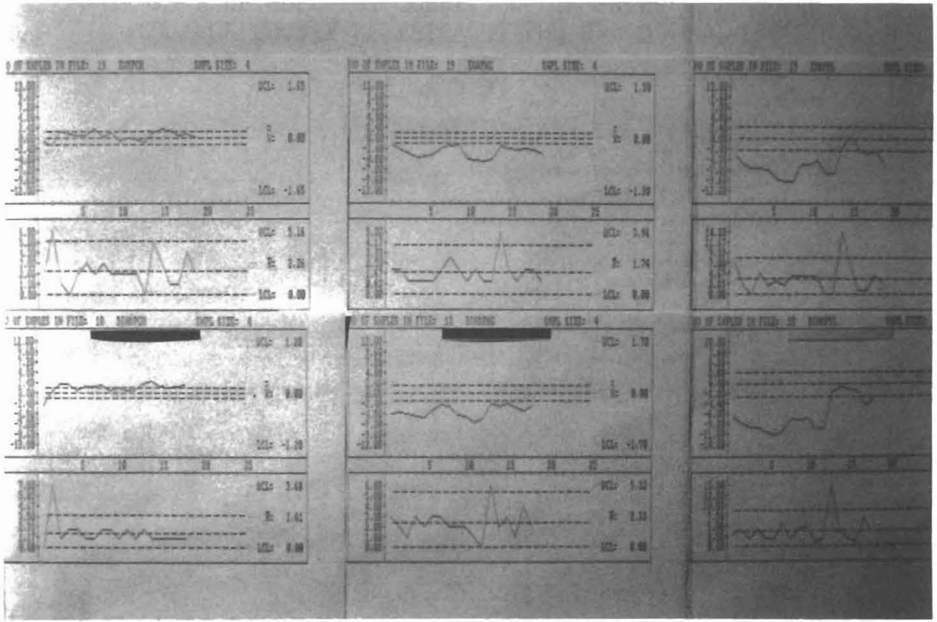
EPIC

CHART OF
RANGES

CONTROL
CHART OF
AVERAGES

DI

CHART OF
RANGES

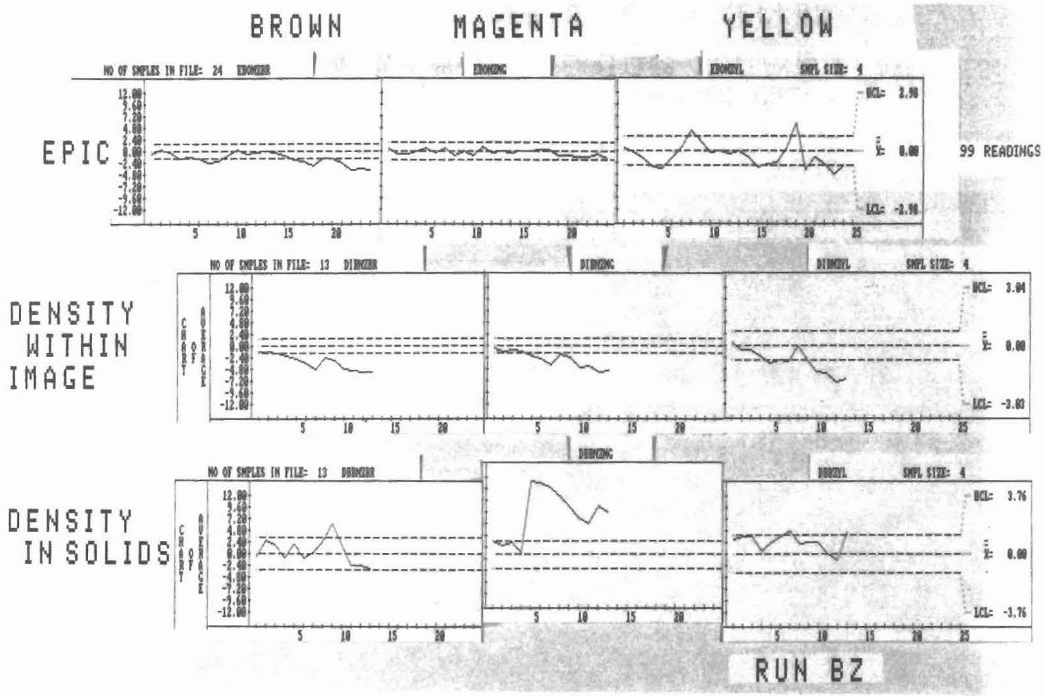


CYAN MAGENTA YELLOW

RUN A

CONTROL CHARTS OF EPIC & DI IN EACH INK.
EPIC DATA IS FROM FIG. 2. NOTE SIMILARITIES IN CHARTS OF AVERAGES.

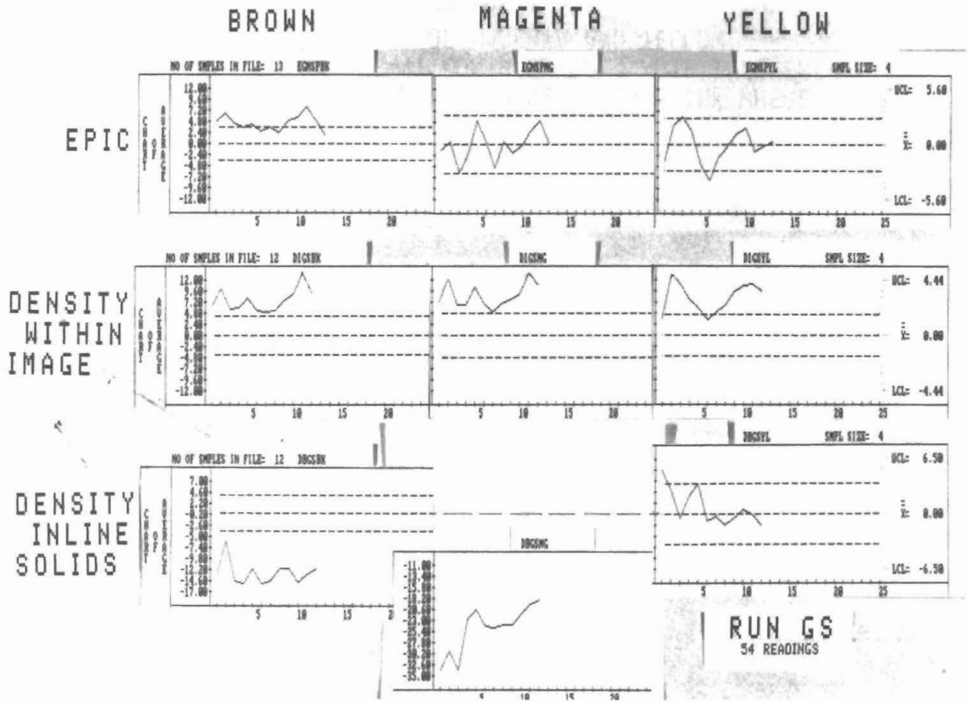
FIGURE 3



RUN BZ

CONTROL CHARTS OF EPIC, DI AND DB IN EACH INK.
NOTE THAT DB DOES NOT CORRESPOND TO IMAGE MEASUREMENTS.

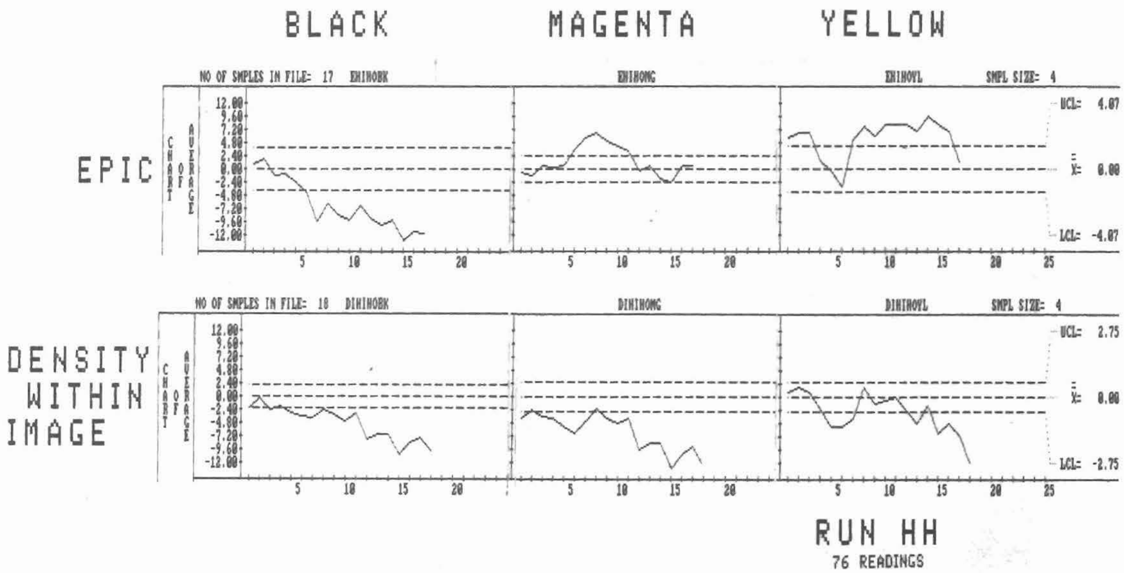
FIGURE 4



RUN GS

CONTROL CHARTS OF EPIC, DI AND DB IN EACH INK.
NOTE THAT DB DOES NOT CORRESPOND TO IMAGE MEASUREMENTS.

FIGURE 5



RUN HH

CONTROL CHARTS OF EPIC AND DI IN EACH INK WHERE BLACK IS A SIGNIFICANT CONTRIBUTOR. NOTE INFLUENCE OF BLACK ON DI OF MAGENTA AND YELLOW.

FIGURE 6