SPECIFICATION AND CONTROL OF PROCESS COLOR IMAGES BY DIRECT COLORIMETRIC MEASUREMENT

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Abstract: Through use of area integration and positioning references, selected segments of color images are colorimetrically measured. Resulting tristimulus color scale values are suitable for specification and communication of target image colors and acceptability tolerances.

Where separations have been made and paper and inks for reproduction selected, quantitative corrections in effective influence of specific inks are derived from the colorimetric measurements of samples compared with those of the target without reference to color bars or special targets. These adjustments are useful at all color correction steps in the process where evaluation and changes can be made. By reducing correction errors or omissions, cost savings are realized in preparing and achieving balance in separations and the plates or cylinders prepared from them as well as in reducing the spread of variations during press runs.

Introduction

Color-measuring instruments were developed and have been applied for nearly 40 years to the specification and control of manufactured products in which color is an important final property. Until recently, the samples to be measured were always prepared to be as uniform and consistent as possible to avoid ambiguity in assigning a color value. Online applications prevent special sample preparation and have led to the recognition that an average color is often a useful representation of the visual assessment of object color. In the mind of the observer, an integration process allows comparison of mottled or patterned color fields. In the same way, two similar images having a wide range of colors within them can be compared for an overall color imbalance.

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HunterLab has adapted its instruments for obtaining dependable, repeatable color measurements directly within process color images. The resulting appearance-related color values can be used to compare image color variations and derive corrective action.

Background

Colorimetry

The identification of color by objective numerical scale values in accord with an internationally recognized model for human color perception has reached a high level of refinement and wide usage throughout the world.[1] The science by which these models were established and the conditions for their proper use are specified is known as colorimetry. Instruments designed to utilize these models operate by providing controlled illumination of an object field and then measuring reflected light in three tristimulus spectral functions which correspond to quantities of three primary colors. The imaginary tristimulus primary colors combine in broad and strongly overlapping spectral functions to match any visible color, as shown in Figure 1. These standard observer curves characterize the visual sensation of color and are clearly distinct from the spectrally isolated red, green and blue separation functions so well known in color printing (Figure 2).

Measurement of any color field with a colorimeter produces three tristimulus values, X, Y and Z, which define the level of each primary needed to visually match the measured color under a specified type of illumination. From the three tristimulus values, any of several color order scales can be computed which relate directly to the position of colors in a color pallette that is a suitable representation of a three-dimensional solid in which each of all of the possible colors have a specific location. Some of these scales (for example, L,a,b as illustrated in Figure 3) have the property that a numerical increment in any dimension or direction in the solid has about the same impact on the visual effect of the mismatch. It is therefore possible to assign tolerances for acceptable color errors that substantially apply throughout the entire color space.[2]

Process Color Printing

Color printing is achieved through complex sequential steps involving the separation of a scene into three images, each representing the contribution of an isolated third of the visible light spectrum. These images are manipulated to compensate for the predictable transfer characteristics of the reproduction process. The images are then imprinted in register on a single sheet of paper, using a specific ink to modulate the reflection of the specific segment of the spectrum associated with that image. Neutral colors, tonal gradations and foundation layers, which contribute achromatic properties to the image, are often added in black as a fourth registered image. Corresponding localized reduction in the colored inks of the other three images are then made. The color control techniques, to correct the unpredictable variations, require a comparison of solid ink optical density of each ink in an acceptable reproduction with the one under examination. More recently, this has been accompanied by monitoring specific halftone targets to identify when conditions in the process fail to render dot sizes in a predictable and standard way.

The last step in all cases is to compare images visually and make any final adjustments necessary to achieve a visually determined objective. It is this step that injects the greatest uncertainties in the process.

For more than 30 years, HunterLab has provided the means to achieve objective confirmation of color judgments in products of all types. We can now announce the promising results of several years' efforts to provide the same assistance to people who are responsible for control of process color through visual judgment.

Direct Image Measurement

How could this goal, which superficially seems hopeless, be achieved in a useful, productive way? The process was divided into three basic categories:

1) Positioning the instrument and the image.

2) Obtaining a colorimetric reading of the image reflectance.

3) Providing useful interpretation of the results.

Positioning of the Instrument on the Image

Anyone attempting to take readings of a process color image will see that position of the instrument on the image affects the value obtained from the readings. Providing a workable method to confine positioning error is key to the success of this system. A number of aids have been developed along with some criteria for selection of image segments which will significantly reduce color-reading errors caused by inaccurate positioning. Figure 4 illustrates the basic instrument configuration.

These are:

a) Visual access to reading area of instrument: The instrument is so designed that the illuminated area is the field of view of the instrument. A window has been provided to permit direct viewing of the area to be measured. This greatly increases visibility to aid in placement of the instrument on the image.

b) Port-down orientation of the instrument: The placement of the instrument on the printed sheet with the viewing port down is a natural convenience in locating the area of the image to be measured. A large sheet can be moved under the instrument rather easily.

c) Vertical movement stand: A stand, allowing vertical movement with smooth motion and parallel contact with the table surface, provides easy merging of the instrument with the desired area of the image.

d) Criteria for selection of image segment: A segment of the image is chosen by following these rules:

   1) Select a part of the image in which the color is important to the customer - for example, flesh tone.

   2) Choose an area rich in no more than three of the four process inks (flesh is often nearly devoid of cyan).

   3) Use a relatively uniform area when available.

   4) Avoid an area which has sharp boundaries between regions highly contrasting with each other.

e) Variable sample area: The size of the illuminated sample area, which defines the area measured by the instrument, is adjusted to match a specific area or feature within the image which has been selected to be the most significant in its color to the observer.

f) Area averaging: This is a unique feature of the instrument function which enables useful and precise color measurement from images. *The instrument simply responds to the composite reflectance of all colors in its field of view.* This avoids the need to assiduously select uniform color areas within an image for control purposes. A further advantage of area averaging is that it allows the use of larger sampling areas. The larger the area, in general, the less sensitive is the reading to small changes in position of the instrument aperture on the image.

g) Precision repositioning aid: Very often, the visual placement of the reading area on the image provides sufficient precision for comparisons involving only a few images. Where comparison of a large number of images over an extended period of time is necessary, an objective positioning aid is provided. This consists of a grid overlay which is used to mark the position of two easily identified points within the image but outside the reading area. These points can be used as registration marks for positioning of subsequent images, providing a quick, efficient means for obtaining readings without variations due to positioning errors.

h) Averaging of successive readings: Provision for accumulating an average of several successive readings of the same image has been made to allow the operator to reduce the variation from placement error even further, if desired.

Obtaining a Useful L,a,b Reading from the Image

In Figure 5, an example of a typical image and its measurement is shown. The flesh tone has been selected as significant, and the subject's cheek was chosen as the image segment to be measured for characterizing flesh tone in this image. The spot size was adjusted to 0.25 inches so that it could be placed on the cheek without including the mouth, earring or eye of the subject. The nearly neutral gray wall was also measured for additional information.

To illustrate the dependability of this method and to portray its significance, four similar images were measured in succession 12 times under two different sets of conditions. Average L,a,b color values derived from the measurements are portrayed in Figure 6, showing a three-dimensional space and the location of the color of the cheek in each of the four images. The a,b plane, alone, illustrates the effectiveness of the measurement, and the results of the 12 sets of repeat measurements are shown in Figures 7a, 7b, and 7c in the two-dimensional a,b plane for simplicity. In Figure 7a, the instrument was placed solely by visual reference on the subject's cheek. The only criterion was to avoid the eye, earring and mouth. Two operators placed the instrument six times each. As can be seen from the grouping of points, the four images are distinctly separated by the measurement, and the placement errors are small compared with the actual color differences.

A smaller spread of a,b positions can be seen in Figure 7b where the same data are plotted using the average position of the groups of five successive points from the series of 12 readings.

A second set of 12 readings on four different but similar images were taken, using an external registration guide, and each point was plotted in Figure 7c. Each image was measured after a quick visual alignment of an image feature with suitable grid markings. No visual check was made of the instrument location on the image. This demonstrates the effectiveness of the simple alignment guide for minimizing the effects of instrument placement variation. The neutral wall values are shown in Figure 7d, and they demonstrate that, with little texture, the image segment is easily measured with a very small uncertainty, even by visual placement. Note that the variations in color of the four images of the wall show relative color shifts similar to those obtained from measuring the cheek.

The user quickly gains confidence in the method best suited to his needs and uses it on a regular basis. A check on precision can be made by repeatedly measuring the same image and verifying the spread in values due to positioning alone.

Once the ability to obtain and rely on L,a,b readings from selected image areas is established, the benefits of such information can be realized.

Interpretation of Color Readings

A press proof or an "OK" sheet is used as a standard or target image color. Measured values of the corresponding area of the standard and various samples will provide objective, numerical comparison criteria. In the example, color space dimensions are used to describe differences or corrections needed.

Suitable tolerances are easily established. Frequently, standards are set with high and low ink levels to illustrate dark and light limits, respectively, around a target image. Often, these are neither symmetrical about the target nor consistent throughout the image. The use of numerical values provides an objective means for selecting and setting allowable limits for the work. This can provide a smoother working relationship between the printer and his customer.

An added dimension in control of color and improved record keeping is also available with this capability. Using color-mixing models, it is possible to compute the necessary mixture of colorants used on the base stock involved to create the composite color averaged over the sampling area of the instrument. A measured image segment (for example, the model's cheek) is made up of, say, 58 percent magenta, 61 percent yellow, and no cyan. (Black is set aside in this example.) Based on measurements of solid ink patches, the maximum influence of each process ink at its nominal density on image color can be recorded and stored in computer memory. If the solid patches measured represent the target densities for the job, then the maximum influence of each ink at that density is described as equivalent to 100 percent dot area coverage. Should the density of the ink increase over the target level, however, the influence of that ink could exceed the 100 percent level. Therefore, we have established a relative scale for correcting color called "Equivalent Percent Dot Coverage" (EPDC). This is computed for each colorant present in the standard image and in the sample image; corrections are then derived by computing the differences. The corrections indicated will vary, depending on the image segment measured. The advantage of this method is that, if two images *look* alike, there will be no correction indicated. For example, the visual match could be a result of dot gain being compensated by a reduction in density in one or more of the inks.

If different segments of the same image are measured and indicated corrections are contradictory, it is likely that changes will be needed in the separation films or in the plates to achieve a satisfactory color match with all parts of the target image. If a set of plates has the capability of producing satisfactory color matches with the target, using the inks and paper involved, the corrective actions indicated will pull it into a good visual match with the target.

"Gray Component Replacement," or GCR, which leaves only three inks on the sheet in any one image segment, provides an ideal set of conditions for the application of this technique. To use the instrument system with conventional process images, segments must be selected to be rich in up to three of the four process inks. In use, one ink is set aside as low in coverage or insignificant in contribution to color in that segment. This is necessary, since black can be reproduced by a mixture of cyan, magenta and yellow. It is not possible to determine how much black has been displaced by the particular ratio of cyan, magenta and yellow that produces neutral. Therefore, the coverage of one of the four must be designated in order to compute the other three.

Having thus computed corrections needed in ink coverages on the job being printed, it is further possible to plot the corrections needed as a function of progress through the job. A record of such information on a typical run is shown in Figure 8. These departures are based on a single measurement of one image segment of the color of the image. When the color matches, the errors are zero. This record is well suited to process control, using statistical quality control techniques, and has been demonstrated as effective feedback for achieving greater uniformity in press performance.

As a spinoff from monitoring job progress in this manner and making corrections during the run to avoid off-color rejections, the record serves as a certification that the job was kept within color boundaries throughout.

Summary

In summary, extracting image color information from the image and deriving net corrective measures provides the printer with a tool by which his efforts to maintain quality are directed at the necessary correction and derived from the part of the signature which is significant to the customer. This approach requires no special targets or control items to be added to the sheets, and it nicely complements the other methods directed at providing more uniform and predictable press performance.

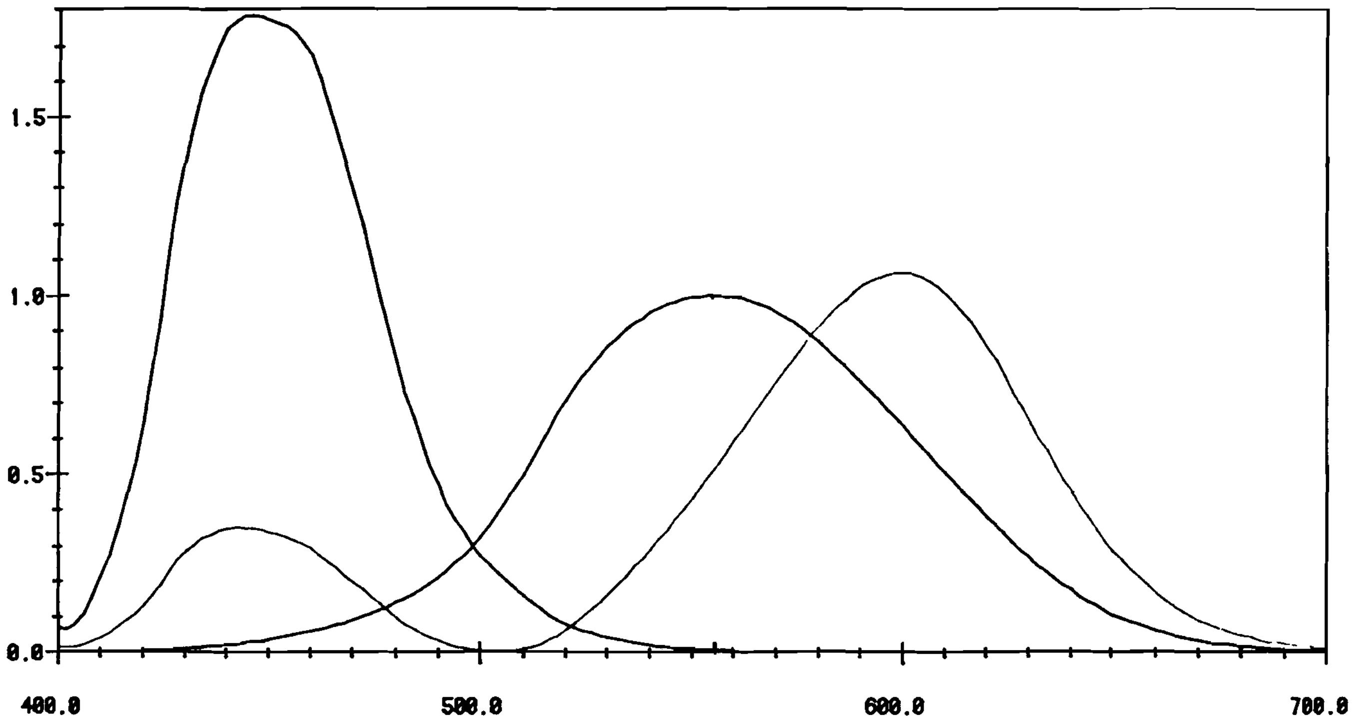
Literature Cited

(1) CIE, International Commission on Illumination
"Colorimetry," Publication No. 15, Paris, 1971.

The C.I.E., Commission Internationale de l'Eclairage, or International Commission on Illumination, in 1931, recommended a model for measurement of human color perception for a two-degree field of vision (the Two-Degree Standard Observer) under several specified illuminants. This and subsequent variations of the model have been adopted and widely used for instrumental measurement of perceived color.

(2) Hunter, R. S.
"The measurement of appearance" (John Wiley and Sons, New York, 1975).

TWO DEGREE STANDARD OBSERVER FUNCTION CREATED IN 1931



WAVELENGTH IN NANOMETERS

FIGURE 1

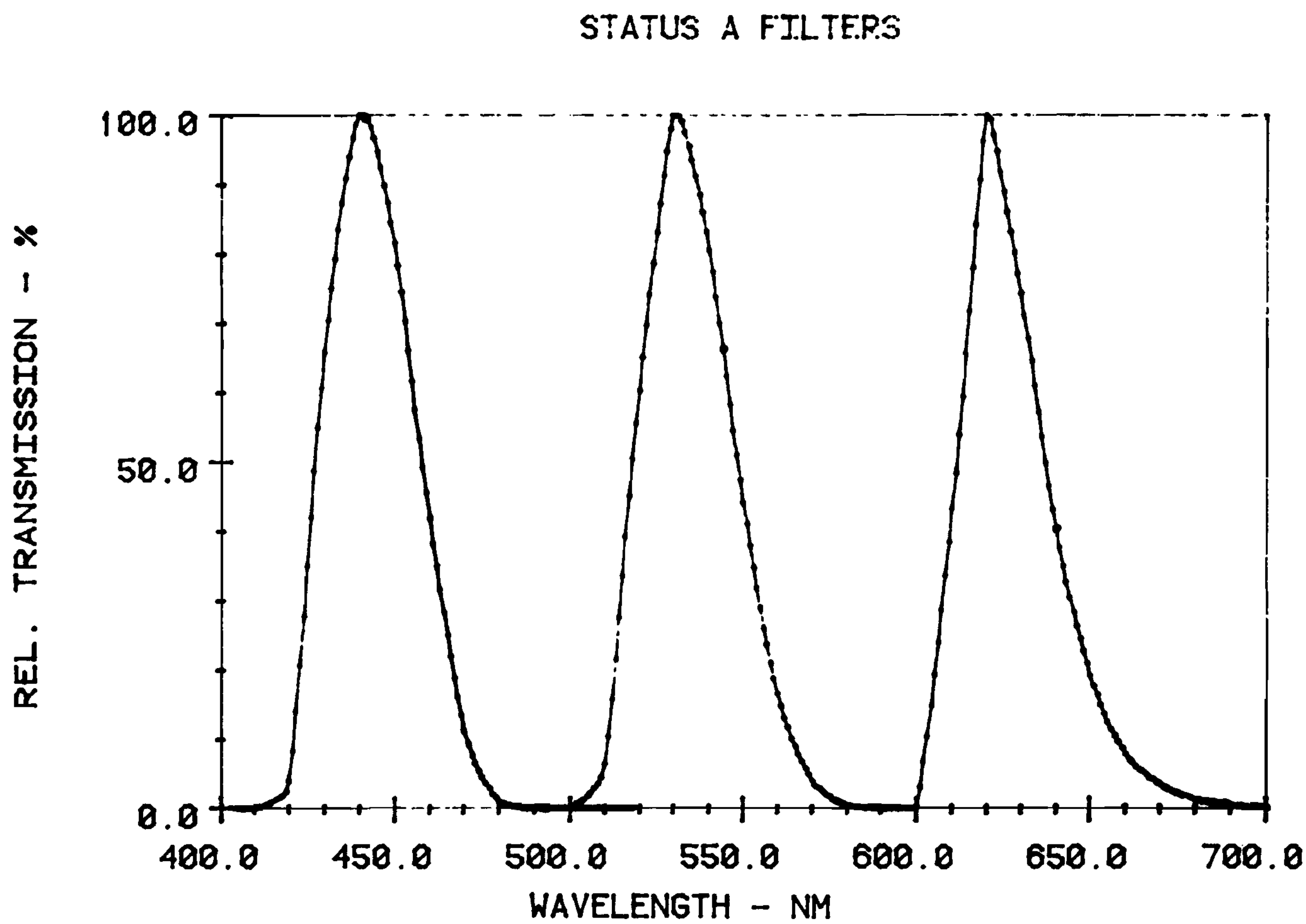

STATUS A FILTERS
100.0
50.0
0.0
REL. TRANSMISSION - %
400.0
450.0
500.0
550.0
600.0
650.0
700.0
WAVELENGTH - NM

FIGURE 2

L,a,b, COLOR SOLID

CIE 1976 L* a* b* (CIELAB)

$L^* = 116\,(Y/Yo)^{1/3} - 16$

$a^* = 500\,[(X/Xo)^{1/3} - (Y/Yo)^{1/3}]$

$b^* = 200\,[(Y/Yo)^{1/3} - (Z/Zo)^{1/3}]$

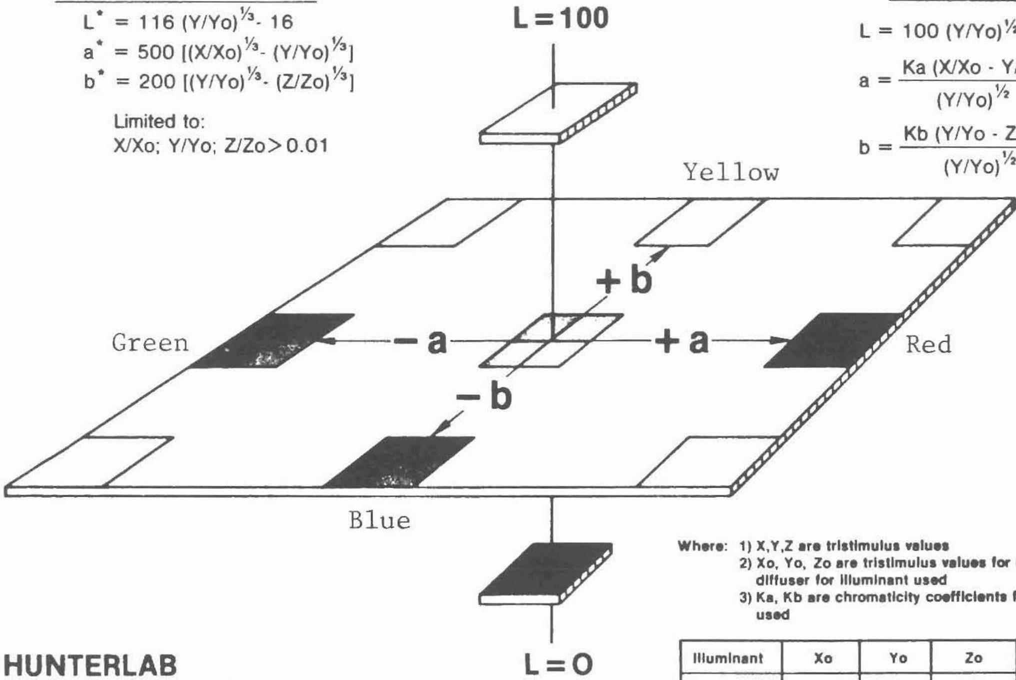
Limited to:
X/Xo; Y/Yo; Z/Zo > 0.01

HUNTER L, a, b

$L = 100\,(Y/Yo)^{1/2}$

$a = \dfrac{Ka\,(X/Xo - Y/Yo)}{(Y/Yo)^{1/2}}$

$b = \dfrac{Kb\,(Y/Yo - Z/Zo)}{(Y/Yo)^{1/2}}$



Where: 1) X,Y,Z are tristimulus values
2) Xo, Yo, Zo are tristimulus values for perfect diffuser for illuminant used
3) Ka, Kb are chromaticity coefficients for illuminant used

Illuminant	Xo	Yo	Zo	Ka	Kb
A	109.828	100.000	35.547	185	38
C	98.041	100.000	118.103	175	70
D_{65}	95.018	100.000	108.845	172	67

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FIGURE 3

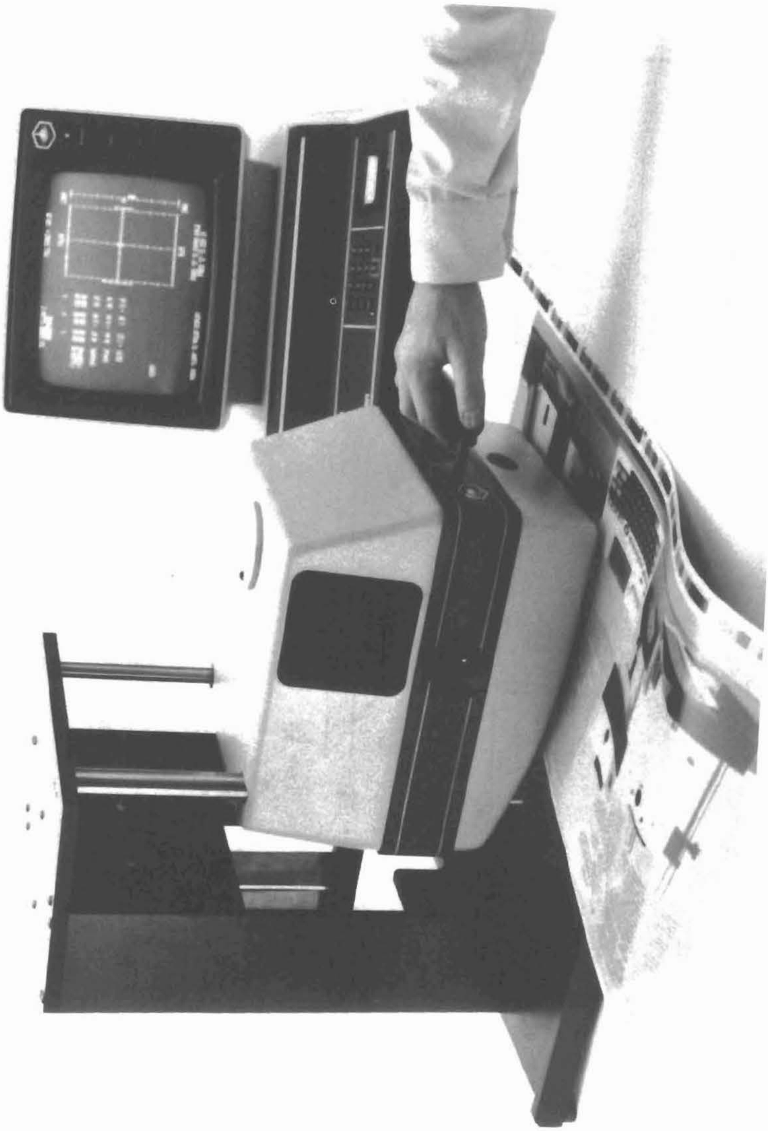
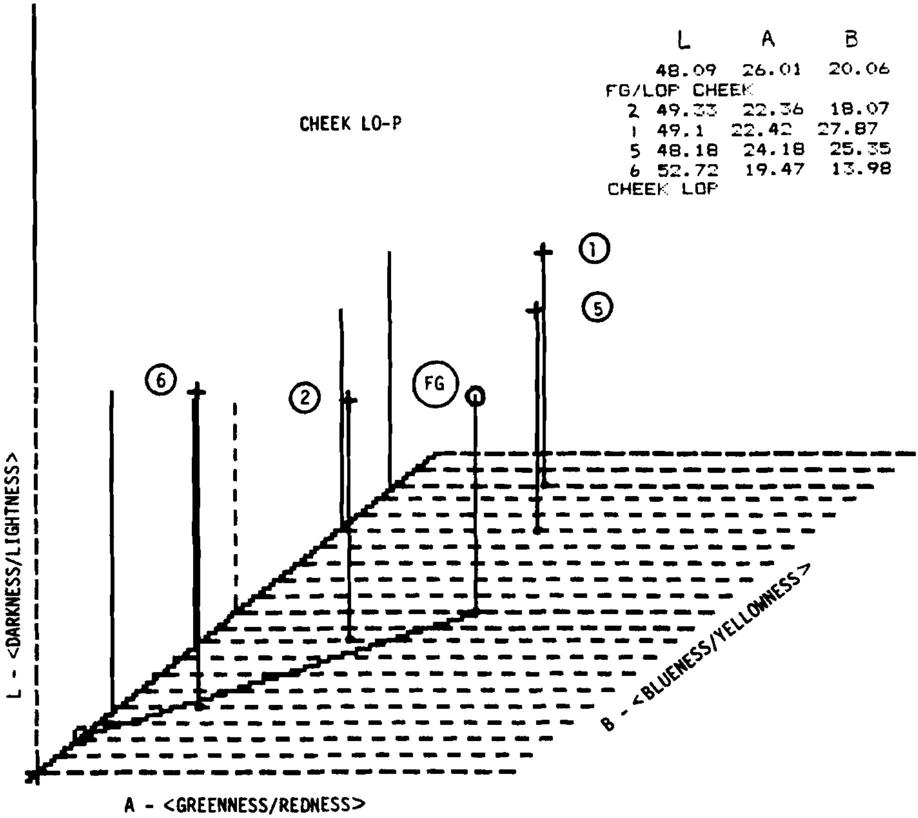


FIGURE 4

FIGURE 5. LO-PAR SAMPLES



THREE-DIMENSIONAL COLOR SPACE

FIGURE 6

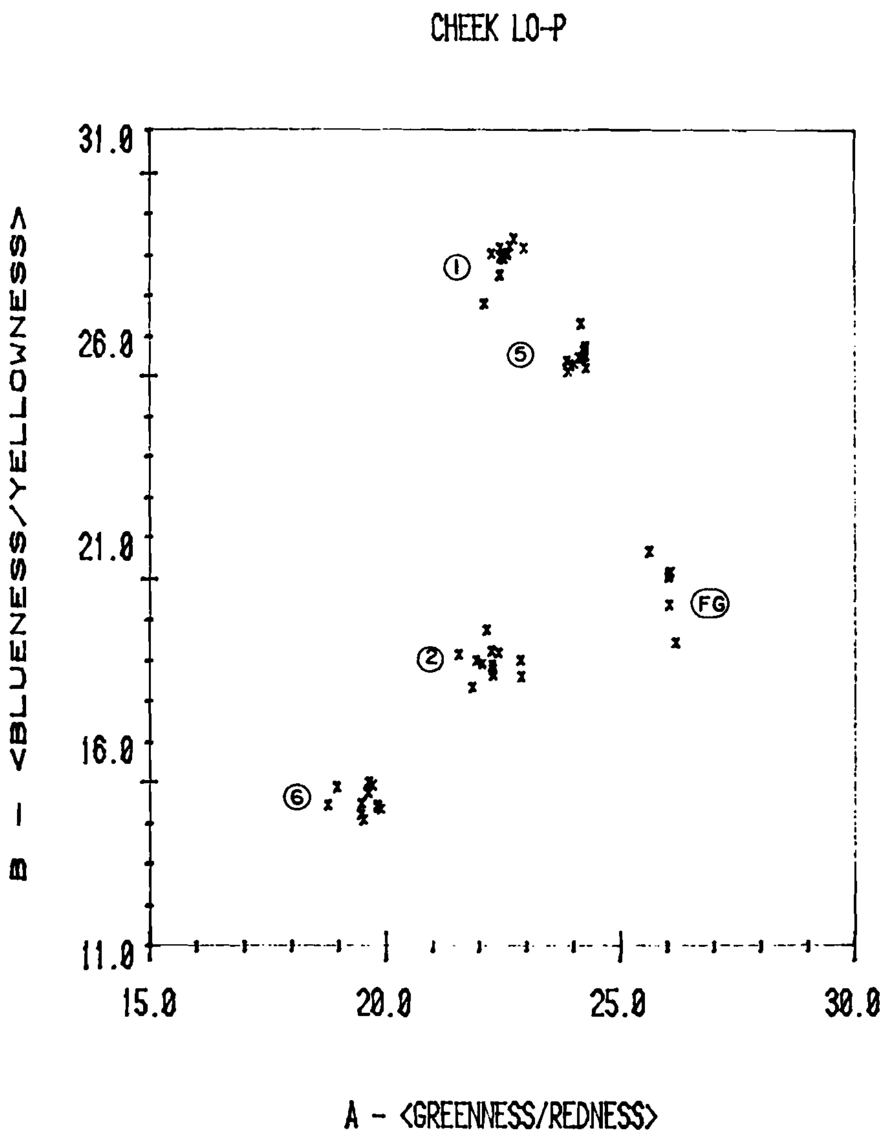
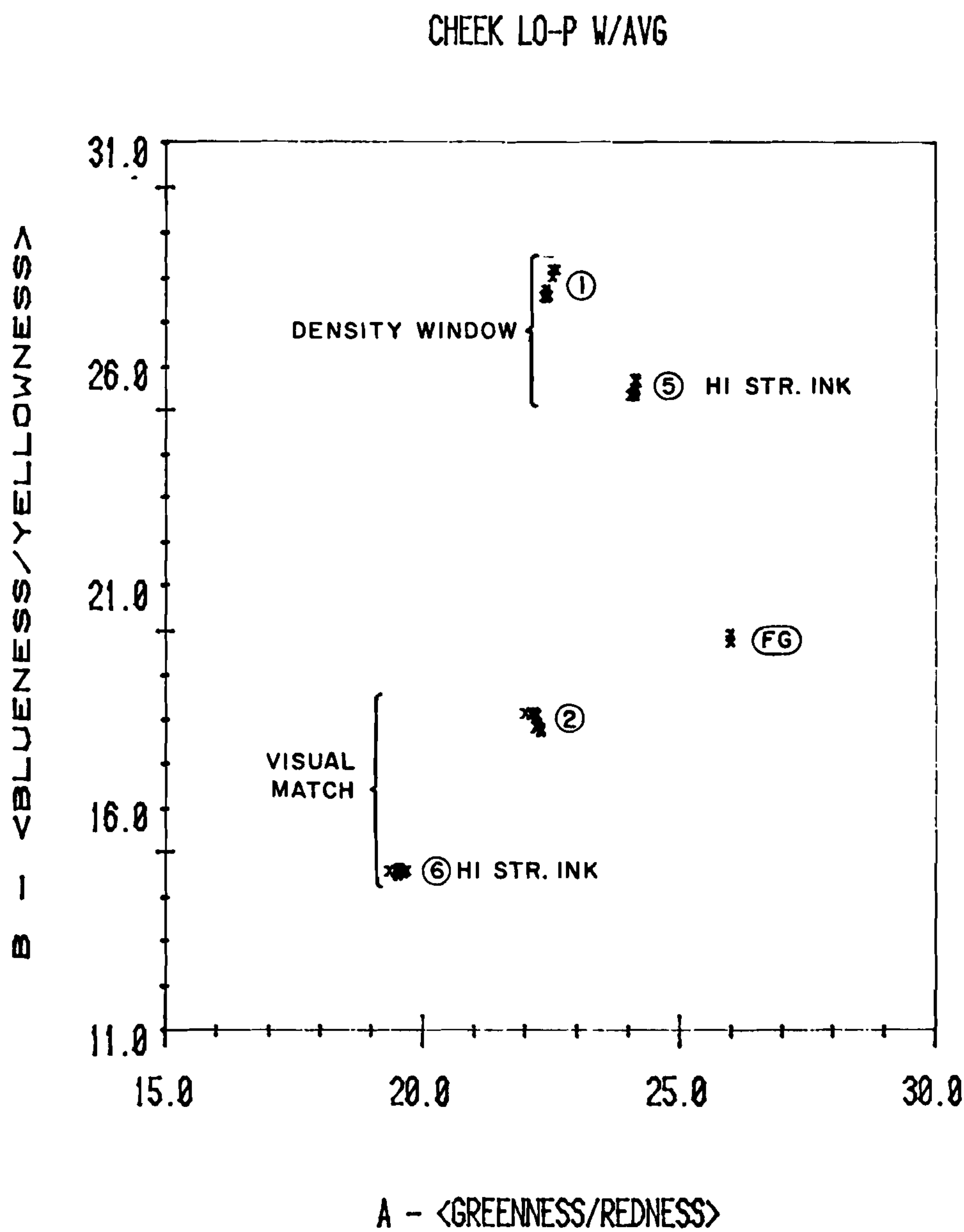
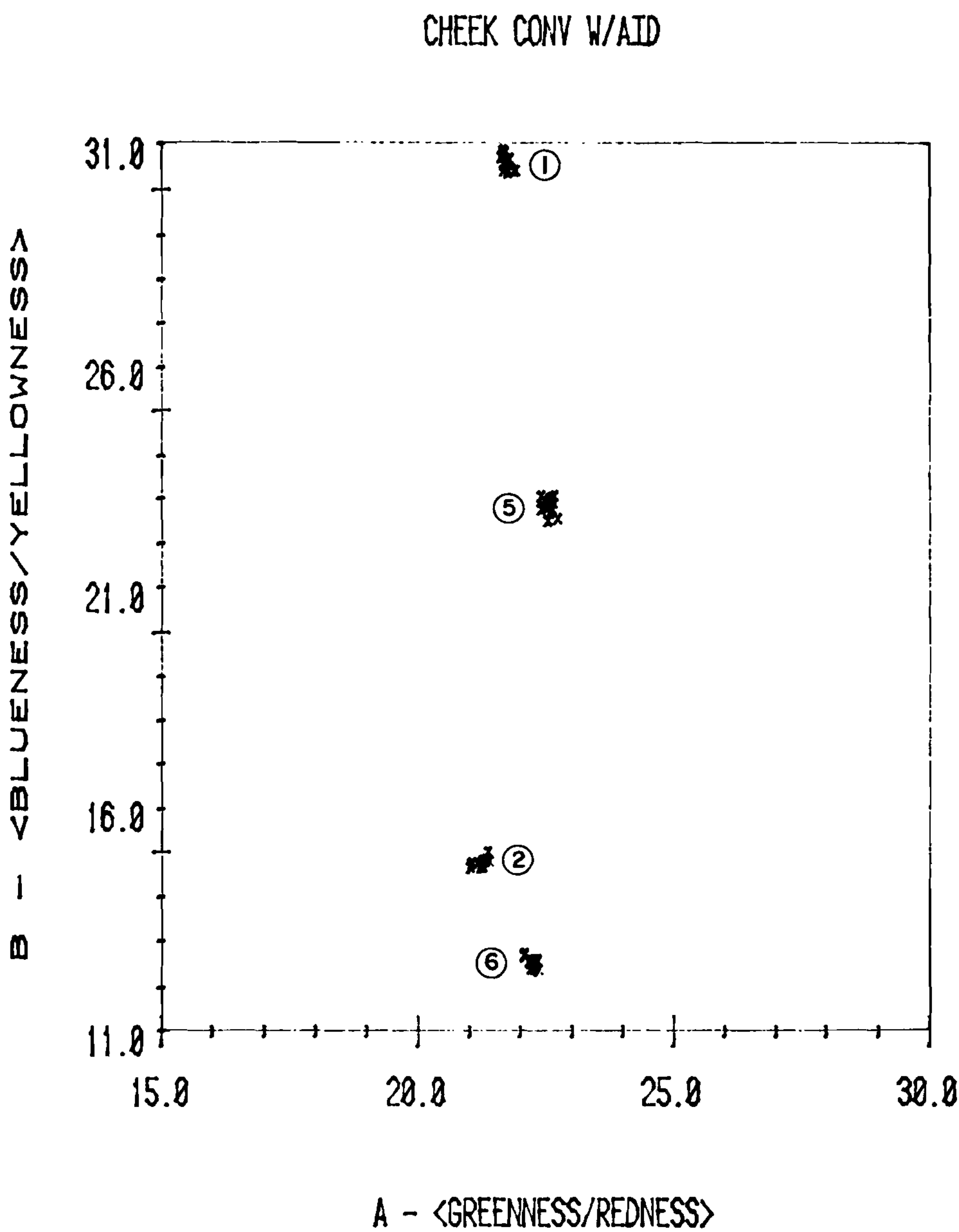

CHEEK LO-P
B - <BLUENESS/YELLOWNESS>
31.0
26.0
21.0
16.0
11.0
15.0
20.0
25.0
30.0
A - <GREENNESS/REDNESS>
①
⑤
FG
②
⑥

FIGURE 7a



CHEEK LO-P W/AVG
31.0
26.0
21.0
16.0
11.0
B - <BLUENESS/YELLOWNESS>
DENSITY WINDOW
①
⑤ HI STR. INK
FG
②
VISUAL
MATCH
⑥ HI STR. INK
15.0
20.0
25.0
30.0
A - <GREENNESS/REDNESS>

FIGURE 7b


CHEEK CONV W/AID
31.0
26.0
21.0
16.0
11.0
15.0
20.0
25.0
30.0
B - <BLUENESS/YELLOWNESS>
A - <GREENNESS/REDNESS>
1
5
2
6
FIGURE 7c

WALL LO-P

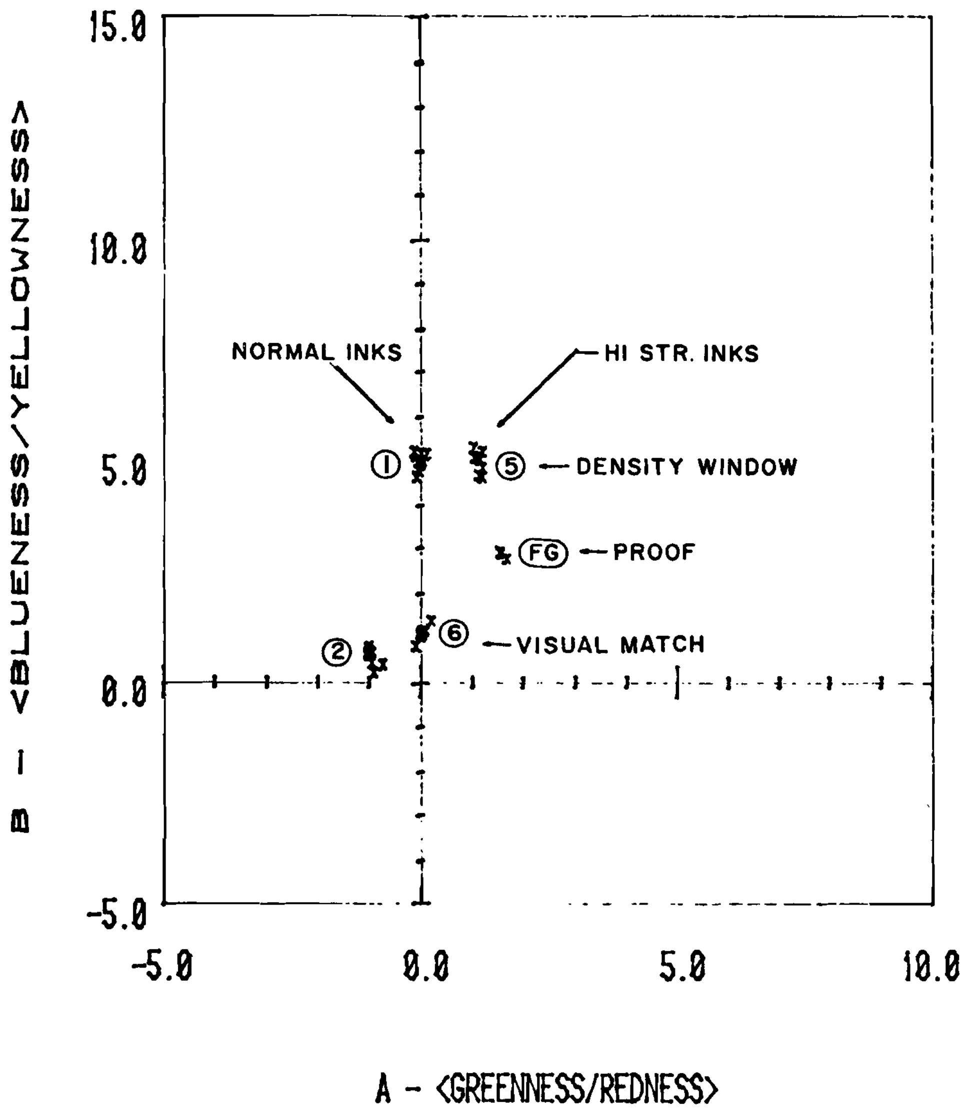
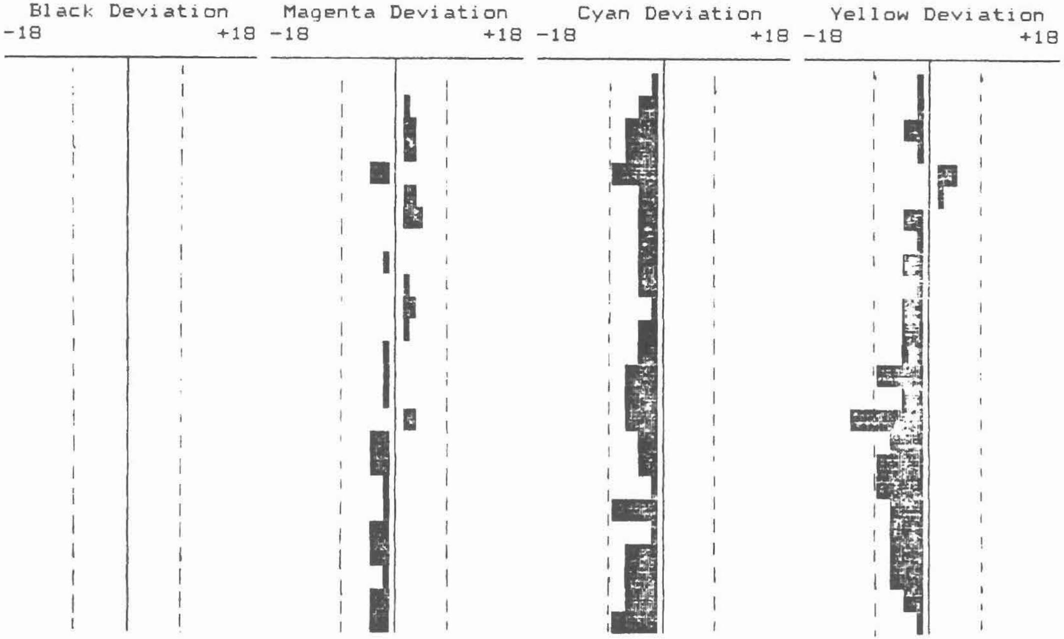


FIGURE 7d

JOB ID: 42 Standard ID: 8

EQUIVALENT PERCENT DOT COVERAGE (EPDC)



CONTROL CHART OF PRESS RUN

FIGURE 8