COLOR CORRECTION OBJECTIVES AND STRATEGIES

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Abstract

An investigation of the theory and practice of color correction with particular reference to the treatment of non-gamut colors. Color correction demands of the printing system, color separation system, original and the customer are examined in terms of the "global" adjustments available through the use of photographic masking or scanner control settings. Two methods of handling non-gamut colors are identified: compress all saturations equally; or, ignore the non-gamut colors and reproduce the others as accurately as possible. Color correction strategies and techniques for achieving given outcomes are presented. The appropriate use of "local" color correction techniques is also discussed.

Reasons for Color Correction

There are two broad reasons for color correction; the first concerns the characteristics of the color reproduction system, and the second concerns the original. In practice, color correction adjustments are not made for one reason independent of the other, but for purposes of analysis it will be useful to separate them.

In the case of the reproduction system, the primary reason for color correction is to compensate for the unwanted absorptions of the yellow, magenta, and cyan pigments used in process color inks. Strictly speaking, the correction is based on the color of the printed ink films; that is, thin layers of the inks that have been transferred to a given substrate.

A secondary set of correction reasons related to the photomechanical reproduction process are those concerning the

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color separation system. The emission of the illuminating light source, the absorption characteristics of the color separation filters, and the absorption properties of other optical elements in the system apply to both scanner and camera methods of color separation. The sensitivity of the photomultipliers in scanners and the sensitivity of panchromatic film used in cameras are the other elements in the color separation system that give rise to correction requirements.

The color correction requirements for both the characteristics of the ink-substrate subsystem and the color separation subsystem may be conveniently monitored through the use of a guide such as the GATF Color Reproduction Guide (Elyjiw and Preucil, 1964). A printed version of the guide is produced under the actual press-ink-paper conditions used in practice by a given plant. The printed guide is then color separated using normal plant procedures. Color correction is adjusted until each separation is an exact record of the amounts of yellow, magenta, and cyan used to print the guide. The effectiveness of this approach has been demonstrated by Warner et al. (1982).

There are, however, two main reasons why exact color correction for the photomechanical process is not always achieved. The first is additivity failure of the inks; that is, the sum of densities of the primary color inks do not equal the actual densities of the red, green, and blue 2-color overprints. In general, additivity failure correction can be achieved via color scanners, but is less likely when photographic masking methods of correction are employed. The other reason why exact color correction is difficult to achieve is proportionality failure; that is, the corrections required for halftone tints of a given process color are not proportional to the solids of the same color. Both scanning and photographic methods sometimes have difficulty in achieving perfect proportionality failure correction.

The other class of reasons for color correction have to do with the original rather than the reproduction process. The first of these reasons concerns the absorption properties of individual colors within the original coupled with the response of the color separation system. If the color separation system recorded colors in a manner similar to the visual perception of those same colors, then there would be no need for this type of color correction. In practice, the color separation system may record visually identical colors differently.

The problem of achieving a visually accurate record of original colors in the separation films occurs for artist-drawn originals, photographic prints and transparencies, merchandise samples, and retouching colors used on photographs. The Eastman Kodak Company (1980) have developed a color guide which is supplied on different types of Kodak color film so that color separation system response may be characterized and adjusted to compensate for the different film types. They have also developed a retouching target designed for testing the color separation compatibility of a color transparency dye set and any given set of retouching colors (Denk and Grover, 1981).

The second, and potentially most difficult aspect of color correction for the original concerns the treatment of non-gamut colors. If non-gamut colors are ignored, they will be reproduced at the same saturation as the nearest gamut color, i.e.there will be no visual difference between the reproduction of the non-gamut color and the nearest gamut color. The alternative color correction strategy is to deliberately degrade the reproduction of colors at the gamut limit so that the non-gamut colors will reproduce just at the gamut limit of the system. This alternative color correction strategy allows the retention of the saturation differences between non-gamut and gamut-limit colors. The drawback, of course, is that gamut-limit colors are reproduced less accurately than would be possible with other color correction strategies.

The final color correction reason, customer changes, often arises from the first two original-related reasons for color correction. Photographs, either transparencies or prints, are themselves reproductions of the original scene. Certain color distortions will be present in the photographs; in some cases these may be artistically-desirable distortions, but in other cases they may not be. An example of undesirable distortion is when a photograph intended for use in a mail-order catalog does not record the color of the merchandise with sufficient accuracy. In this case the customer will often submit an example of the merchandise along with the photograph and instruct the color separator to reproduce the photograph, but to use the merchandise sample as a guide when color correcting that part of the original. This type of customer change is that specified before the separations and proofs are made.

Customer changes and corrections frequently occur after the proofs have been made. Some of these corrections may be due to inadequate color correction of reproduction system-related requirements. More often, corrections are needed because of original-related reasons. Apart from the fact that some colors are too saturated to be accurately reproduced, some tones, especially in transparencies, are too dark to be accurately reproduced. The exact saturation and tonal compressions required for a given original are not known with certainty; therefore, the proof represents a best approximation on the part of the color separator. The customer, on seeing the combined effect of saturation and tonal compression for the first time in the proof, is now able to exercise the appropriate visual judgment in order to maintain the visual integrity of the reproduction. For very demanding quality requirements, it is virtually impossible to specify these corrections before a proof is available.

To summarize the section concerning the reasons for color correction: color reproduction system-related color correction requirements are fairly well understood and can be accurately monitored via established methods; original-related color correction requirements are only partially understood, and while some may be predicted in advance, others can only be determined after a proof has been made.

Color Correction Techniques

There are two general approaches to color correction: global and local. The global approach uses techniques that influence the color correction of the entire reproduction. Photographic masking and the electronic circuits of color scanners are examples of the global approach. Local techniques are directed at the color correction of specific areas within the reproduction. Most local techniques first rely on the manual isolation of the area to be corrected. The correction itself may then be achieved by chemical, photographic, or electronic methods.

Many possible methods of photographic masking for color correction have been suggested (Preucil, 1949; Nash, 1965). These methods can be divided into two categories: masks made before the separations ("pre-masking"), and those made after the separations ("post-masking"). The pre-masking approach relies on filter selection (including the use of split-filter strategies), exposure and developing time to control the type and amount of correction offered by the mask. Masking strength is limited because the masks reduce the contrast of the image. The two-stage method of post-masking eliminates the contrast reduction problem at the expense of an extra step. Technically, six masks should be made to color correct a given reproduction. Two masks are used on each separation to correct for the unwanted absorptions of each of the other two process colors. In practice, the unwanted red and green absorptions of yellow pigments, and the unwanted red absorption of magenta pigments are so minor that the masks for correction of these absorptions are often omitted. The blue absorption of magenta and cyan inks are often "balanced" with the green absorptions of the same inks so that only one mask is required for the blue filter separation.

Color scanners have evolved considerably (Preucil, 1974; Field, 1986) but in most cases their color correction circuits still mimic the effect of photographic masking. Voltages are added and subtracted to achieve color correction in a manner similar to the addition and subtraction of densities in multi-stage masking processes.

Electronic correction affords greater flexibility and control than photographic methods. Both negative and positive signals can be used to precisely control the "wanted" and "unwanted" signals for both the primary process colors and the secondary color overlaps. Individual control of the red, green, and blue overlap secondary colors allows color correction for additivity failure. Such correction is difficult to achieve by photographic masking methods.

The oldest method of local correction involves first covering the correct areas of a separation film (or plate) with an etchant-resistant barrier. Next, a chemical is applied to reduce the tonal value or dot area of the unprotected area. For halftone film dot area modification, the degree of change is constrained by the loss of dot density that accompanies the reduction in dot area.

The "dry" dot etching method involves the use of a supplementary exposure through an isolation area mask when producing contact films. The isolation mask may be produced by manual outlining or, in some cases, by combining the appropriate number of negatives and positives and exposing the mask onto contact film. This method is capable of a wide range of tonal manipulation but uses considerably more film than other methods.

The electronic method of local color correction utilizes color imaging systems. Color change is achieved by redefining the digital color values that reside in the computer's memory for a given area. Virtually unlimited color shifts may be achieved by this method. The isolation mask signal may be prepared, in some cases, by electronic methods, or by manual outlining. Zoom controls simplify the manual outlining task on color imaging systems.

Discussion

The color correction objectives for the characteristics of the color reproduction system are well defined. Color correction objectives for the original are also fairly objective in the case of color distortions related to the response of the color separation system. Color correction requirements related to the reproduction of non-gamut colors and to customer alterations are less well defined.

Local color correction techniques may be used to achieve any degree of adjustment for any given color in the reproduction. The problem with local correction techniques is the time required to manually isolate the local area in question.

The key objective in applying color correction is, therefore, to use global correction techniques in such a manner so as to minimize the need for the use of supplementary local correction techniques. In order to achieve this objective it is necessary to look beyond the correction required for the reproduction system and to incorporate corrections required for the original.

Two color correction strategies were chosen for evaluation. In practice, it is likely that these strategies would represent the color correction extremes for global correction. The strategies are:

Strategy A: Adjust the correction to accurately reproduce the gamut-limit colors and ignore the non-gamut colors. The corresponding reproduction will compress the saturation differences between gamut and non-gamut colors.

Strategy B: Adjust the correction so that the non-gamut colors are reproduced just at the gamut boundary. The subsequent reproduction will retain the saturation differences between non-gamut and gamut colors at the expense of reproducing gamut colors at reduced saturation.

Experimental

In order to assess the relative merits of the different color correction strategies, a research project was developed. The following procedure was followed:

1. A 3M Matchprint proof original was generated that consisted of solid yellow, magenta, and cyan primaries, and red, green, and blue secondaries. The proof was made to SWOP specifications. The transition gamut colors between a secondary solid and a primary solid were achieved by combining a solid primary with decreasing percentages of the other primary that made the secondary color. That is, the transition between green and yellow was characterized by ten colors made of solid yellow and screen tints of cyan in the following percentage values: 90, 80, 70, 60, 50, 40, 30, 20, 10, and 5.

2. Non-gamut colors (identified in Table III) were mainly selected from the Toyo Ink Color Finder books. The criteria used for selection was that they have approximately the same maximum density as the nearest 3M Matchprint proof colors and that they lie outside the available gamut. A GATF Color Triangle was used to describe the proof gamut and locate the selected non-gamut colors. (Figure 1)

3. Gamut and non-gamut colors together with a GATF Color Reproduction Guide and a gray scale were assembled to form the test target for color separation. (Figure 2)

4. Continuous tone color separation negatives were made from the original via a process camera. Gamma 1.0 pre-masks (i.e., positives) were made from each separation.

5. Separation negatives and pre-masks were combined in the usual manner in order to generate the correction masks for the two-stage masking method. The initial strategy envisioned correction masks for: blue absorptions of magenta and cyan (the yellow printer mask); green absorption of cyan (the magenta printer mask); and, the red absorption of magenta (the cyan printer mask).

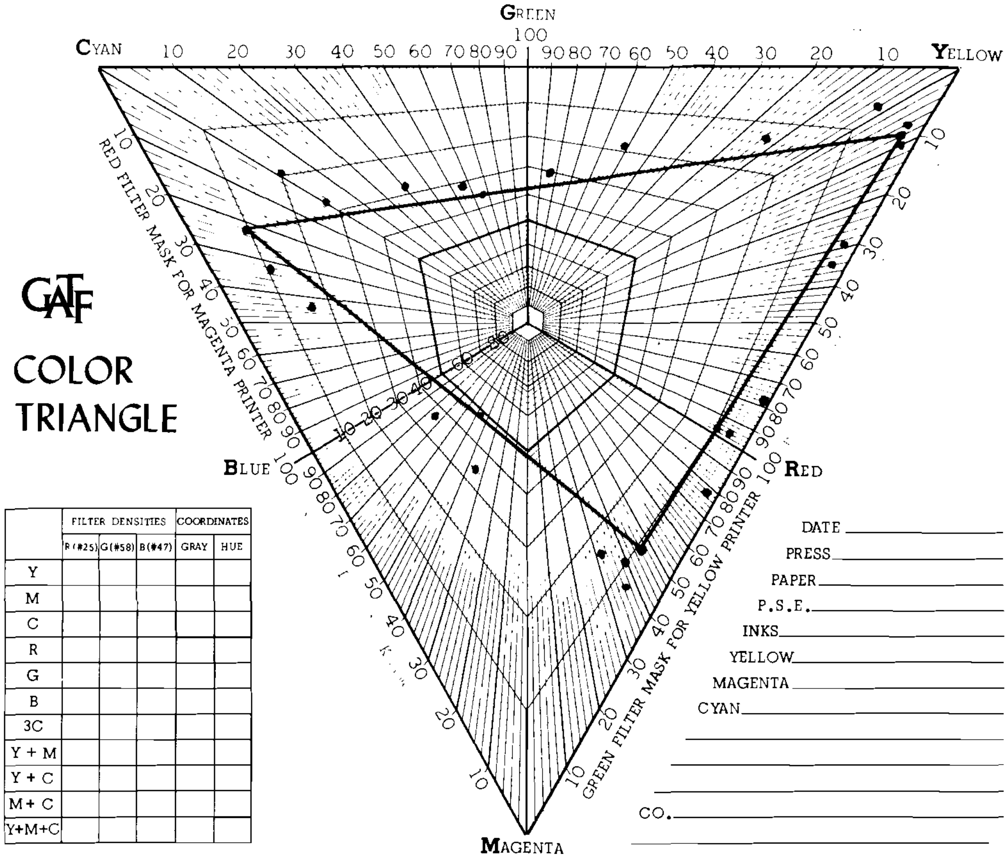

Figure 1. GATF Color Triangle Showing Gamut Boundary and Non-Gamut Original Colors

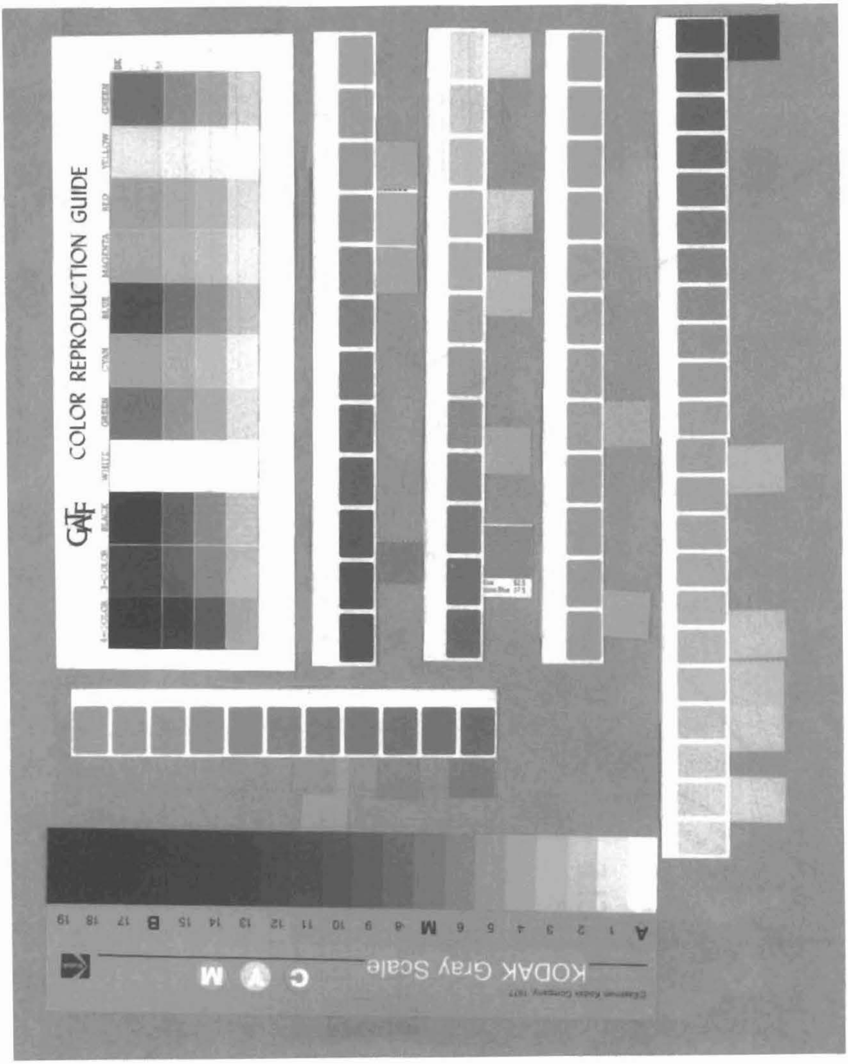

Figure 2. Test Target Layout

6. The first set of correction masks was made to satisfy the correction requirements of the solid yellow, magenta, and cyan colors. That is, the color patch densities of any two primary colors should equal the density of the white patch on the separation negative.

7. A supplementary mask was made to correct the red absorption of yellow (i.e., an extra cyan separation mask). An alternative mask was made to correct the green absorption of the overprint green solid. This mask (i.e., an alternate magenta separation mask) over corrected cyan.

8. A second set of correction masks was made with lighter densities compared to the first set. The mask strength was adjusted so that the separation negative densities of selected non-gamut colors were made equal to the density of the white patch on the corresponding separation.

9. The first set of masks (including the supplementary cyan mask) were combined with the appropriate separation negatives and used to produce screen positives. An alternate magenta positive was made with the alternate mask in place. The first set of correction masks were replaced with the second set of masks and a new set of screen positives were produced.

10. The original was reseparated on an analog color scanner. Color correction controls were adjusted so that the dot area in the "unwanted" primary and secondary color patches for each separation were equal to the dot area in the white patch.

11. Contact negatives were made from the camera screen positives. They were assembled with the scanned separations and proofed onto 3M Matchprint proofing material.

12. A colorimeter was used to measure the non-gamut colors and the nearest gamut colors on both the original and the reproduction proofs. The color differences between the non-gamut and corresponding gamut colors were computed via the FMC II equation. Color differences between selected original and reproduction gamut-limit colors were also measured.

Results

The first level of analysis concerns the GATF Color Reproduction Guide. If this guide is reproduced accurately, then the gamut-limit colors should also be reproduced accurately.

The solid yellow, magenta, and cyan colors could be accurately reproduced by either the photographic or electronic methods of color separation. The mask to correct the red absorption of yellow overcorrected the red secondary color in the camera separations. The green secondary color in the magenta camera separation could only be corrected by overcorrecting the cyan patch. The electronic scanner had no difficulties in handling these additivity failure correction problems. The film dot values in primary and secondary solids of both the original film and the separations are presented in Table I.

Neither method of color separation and correction was capable of handling proportionality failure correction. If correction was adjusted to satisfy the correction requirements of the primary tint values on the GATF Color Reproduction Guide, then the primary solid colors were overcorrected. Correction of primary color halftone tint areas was better with photographic methods. Scanner correction circuits are presumably linear, whereas the photographic method uses the non-linear curve of the masking film to apply different amounts of correction to different tonal values. Table II presents the film dot values for the primary color tonal steps in both the original films and the separations.

The initial conclusion from the first level of analysis was that the gamut-limit colors would not be accurately reproduced because of additivity and proportionality failure. The next conclusion was that additivity and proportionality failure correction could not be achieved by either method without overcorrecting solids.

The second level of analysis concerns the color difference calculations. The differences between the original proof of the Color Reproduction Guide and a control proof made of the original films when making the proofs of the separations, were slight. The differences ranged from a DE of 2.60 for yellow to a DE of 11.09 for blue.

Table I

Color Correction

Color Correction of the Solids of "Unwanted"
Colors in Yellow, Magenta, and Cyan Separations

Yellow Separation	White	Cyan	Blue	Magenta
(Camera)	0%	0%	0%	0%
(Scanner)	0%	0%	0%	0%

Magenta Separation	White	Green	Cyan	Yellow
(Camera #1)	0%	6%	1%	0%
(Camera #2)	0%	2%	-0%	0%
(Scanner)	0%	0%	0%	0%

Cyan Separation	White	Magenta	Red	Yellow
(Camera)	0%	0%	0%	0%
(Scanner)	0%	0%	0%	0%

All values are recorded as percentage dot areas.

Table II

Color Correction of the Solids and Tints of the "Unwanted" Primary Colors in Yellow, Magenta, and Cyan Separations

Yellow Separation		Camera	Scanner
Magenta	Solid	0%	0%
Tint	3/4	1	10
Values	1/2	2	11
	1/4	2	7
Cyan	Solid	0%	0%
Tint	3/4	0	-2
Values	1/2	0	-2
	1/4	0	-2
Magenta Separation			
Yellow	Solid	0%	0%
Tint	3/4	0	1
Values	1/2	0	1
	1/4	0	2
Cyan	Solid	1%	0%
Tint	3/4	4	4
Values	1/2	5	4
	1/4	3	0
Cyan Separation			
Yellow	Solid	0%	0%
Tint	3/4	0	0
Values	1/2	1	2
	1/4	1	2
Magenta	Solid	0%	0%
Tint	3/4	3	3
Values	1/2	5	4
	1/4	4	3

All values are recorded as percentage dot areas.

Table III shows the color differences between the non-gamut and gamut-limit colors for the original colors and the proofs of the separations. Separation set A represents the "correct for the gamut-limit colors" strategy. Separation set A' uses the yellow and cyan from set A together with the alternative magenta that provides improved correction of greens. Separation set B represents the "correct for the non-gamut colors" strategy.

When the masks were being made, it became apparent that if correction was adjusted to suit one non-gamut color, the resulting correction would not necessarily be ideal for other non-gamut colors. In other words, it was impossible to achieve ideal correction for all colors through the exclusive use of global correction techniques. This conclusion was reached for both the photographic masking applied to the test original and, in a separate study, for electronic correction applied to a series of Kodak Q-60 Color Reproduction test transparencies.

The key non-gamut colors that were selected as the color correction "target" colors when the B set of separations were made are indicated in Table III with an asterisk. The reproduction accuracy of the nearest gamut colors (plus a representative yellow-orange color) are presented in Table IV. The key, and expected, finding is that, in general, color correction strategy B more accurately retains the color differences between the selected non-gamut and gamut-limit colors, whereas color correction strategy A more accurately reproduces the gamut-limit colors.

Conclusions

While it is clear that the A and B color correction strategies produce different results, it is not clear which produces the better results. In general, research literature (Pearson, 1971) has supported the use of strategy B when non-gamut colors are present in the original. Strategy A would seem to be preferred when there are no non-gamut colors in the original or the gamut-limit colors in the original are critical and must be reproduced as closely as possible.

Proportionality failure and additivity failure limit the degree of correction that may be achieved by either photographic or electronic methods. The scanner used in this research project was an analog machine and while it provided excellent additivity failure correction, it did

Table III

Color Differences Between Non-Gamut and Gamut-Limit Colors

Non-Gamut Color Identity	DE Original	DE Sep.A	DE Sep.A'	DE Sep.B
Green-Cyan				
CF 8307	55.30	20.61	14.37	17.99
CF 8320	37.79	21.31	13.35	21.96
CF 8362	24.17	30.48	23.63	27.02
CF 8348*	51.20	32.73	26.51	45.09
Cyan-Blue				
CF 8471	25.21	47.75	37.58	50.65
CF 3899	25.96	37.17	30.29	46.39
CF 8560*	29.33	9.36	8.82	32.08
Blue-Magenta				
CF 8570	36.02	20.32	27.54	25.50
CF 8012	20.10	23.40	25.74	17.83
P Rhodamine*	21.78	10.27	14.30	18.45
CF 8023	10.74	1.50	4.04	7.82
Magenta-Red				
CF 8065	13.74	8.44	7.65	8.51
CF 8096	9.33	3.07	2.80	6.47
Red-Yellow				
CF 2121	31.69	64.52	61.48	73.84
CF 8163	31.61	67.62	68.07	66.60
CF 8180	16.28	35.20	35.23	36.74
CF 8177	10.84	18.62	32.34	37.13
CF 8196	7.66	9.68	9.81	9.28
Yellow-Green				
CF 8206	30.70	24.37	21.79	21.30
CF 8223	45.27	58.56	51.47	47.14
CF 8238	25.39	31.95	28.00	24.57
CF 8266	28.62	32.79	32.55	29.51
P 361C	9.72	3.45	3.40	2.71

*Color Correction "Target" Color for Separation Set B.

Table IV

Original vs. Reproduction for Selected Gamut Colors

	Blue DE	Green DE	Magenta DE	Orange DE
Separation A	46.03	38.04	34.59	28.79
Separation A'	45.83	38.23	33.15	28.17
Separation B	93.89	34.17	35.65	33.51
	DL	DL	DL	DL
Separation A	22.23	3.65	10.92	10.32
Separation A'	20.60	9.14	8.16	10.33
Separation B	25.20	-4.19	1.12	13.09
	YB	YB	YB	YB
Separation A	24.18	16.94	3.38	-17.23
Separation A'	23.60	20.07	0.24	-17.24
Separation B	42.09	10.70	12.55	-16.71
	RG	RG	RG	RG
Separation A	32.25	33.87	-32.65	-20.63
Separation A'	33.45	31.23	-32.13	-19.74
Separation B	80.05	32.18	-33.35	-25.93

not provide adequate proportionality failure correction. It is the author's opinion that digital scanners probably provide good proportionality failure correction. A lookup table would seem to allow modifications of the type required for this correction.

The global correction afforded by either photographic masking or electronic color scanners is not selective enough to provide individual correction control for more than a few non-gamut colors. This problem is probably not serious for photographic originals because all non-gamut colors in a given original are made of the same yellow, magenta, and cyan dyes; therefore, they will all tend to respond the same. For retouched photographs or artists' originals, supplementary local correction techniques may be unavoidable in order to produce a satisfactory reproduction of non-gamut colors.

Today's significant use of color video monitors on color scanners represents one method of making the color correction control-setting decisions. The effect of given settings can be observed on the monitor before the high resolution image scan is made and the separations recorded on film or magnetic disk.

Recommendations

Perhaps the best method of assessing the effect of color correction adjustments is to use a color scanner equipped with an accurate color video monitor. The monitor provides a proof; and while it will lack certain characteristics of the final reproduction, a skilled operator can accurately assess the image and make appropriate scanner control adjustments.

When using a scanner without a color video monitor, or using non-scanner methods of color separation, test targets should be used for initial color correction setup. Both a set of original test transparencies and a series of printed Color Reproduction Guides are required to implement the following recommendations:

1. The first step in establishing a color correction procedure is to produce the closest possible reproduction of a color transparency test target such as the Eastman Kodak scanner test target (Maier and Rinehart, 1988). Both color correction and gray balance controls are adjusted to achieve this reproduction.

2. Next, a GATF Color Reproduction Guide, produced under the conditions used to reproduce the test target, is color separated with the same color correction settings used in the first step. Dot value in solids and tints of the primary, secondary, and 3-color areas on the guide are measured and recorded. In the case of a color scanner, the values may be measured without actually having to made the separations.

3. Color Reproduction Guides produced under other typical manufacturing conditions are placed in turn on (for example) the scanner. The gray balance controls are adjusted to achieve the same values in the 3-color patch as recorded in the initial setup. Color correction controls are then adjusted so that the solid and tint values of the primary and secondary colors have the same relationship to the white and 3-color control patches as they did for the initial setup. the scanner control settings for the initial test transparency for all Color Reproduction Guides are recorded for future reference.

4. The next color transparency test target is placed on the scanner and the gray balance controls adjusted until the neutral grays in the second transparency reproduce with the same dot values as the first transparency for the initial reproduction system. Adjust the color correction controls to produce the smallest color difference in the reproduced colors between the first and second transparencies. Repeat this procedure for all other versions of the original test target. Record the color correction and gray balance settings.

5. Finally, set the color correction and gray balance controls for another Color Reproduction Guide. Adjust the color correction and gray balance controls by an amount equal to the difference between the settings for the first test original transparency and the second test original transparency for the initial color reproduction system. Record the color correction and gray balance control settings. Repeat for the other test original transparencies and the other Color Reproduction Guides.

Practical Considerations

If the recommended calibration procedures from the previous section are followed, the color separator should have a selection of color correction and gray balance settings for different reproduction conditions and types of originals. If there are four reproduction systems and five different originals, there will be twenty different recommended initial settings. If a digital scanner is used then it should be relatively simple to set the scanner for any one of these conditions. For other types of color separation systems, the number of possible setups should be reduced to the most common for that plant.

Apart from color correction and gray balance adjustments for a given color reproduction system and type of original, tone reproduction adjustments will also have to be made. The adjustments will be made to both compensate for press dot gain and to suit the nature of the original. Highlight, middletone, or shadow detail in the original will generally be emphasized according to the "interest area" in the original.

The actual color correction requirements of a given original may vary from the initial setup. Some of the reasons that will influence the deviation from initial settings includes: size and shape of the critical color detail; size, shape, and color of an area surrounding the critical color; the presence of merchandise samples that are used as color guides; sharpness differences between original and reproduction; fluorescent or other non-predictable colors in the original; size differences between the original and the reproduction; the presence of critical gamut colors and non-critical non-gamut colors; and, customer requests for specific distortions.

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