AN OPTIMIZED COLOR REPRODUCTION METHOD INCORPORATING SUBJECTIVE AND OBJECTIVE CONTROLS

Dennis B. Miller*

Abstract: A process based on objective measurements has been developed permitting subjective control of average output of a color reproduction system. The analysis, development, and testing are discussed. A method for measuring the intent of the buyer (editor, art director etc.) was developed and related to the separation process. Similarly a feedback loop was devised which relates measurements of press sheets to the intended result and feeds corrective data to the separation process when necessary. Masking is also adjusted to the original and firmly controlled. Quality control procedures are built in. A data base allows for multiple optimizations which may: standardize the output of different systems; and satisfy different objectives such as cost, time, or quality in the same system. Once optimized for color balance and overall density, specific production samples which best represent the true output of the system can be identified. Such samples can be evaluated with existing technology for common faults beyond color balance and density. Control functions can be operated from distant or centralized stations. Although designed to meet newspaper requirements, the subjective control afforded by this process also suggests application in areas where critical color control is essential.

Introduction

Difficulties with subjectivity result, in part, from failure to accept the assumptions of color reproduction for what they are: conditions which may not be met in practice.

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*OptimAll Color

A new approach to color reproduction (Miller, 1982) has been devised to deal more effectively with the subjective nature of color, and those responsible for determining color content. In this approach, objective measurements serve a single function: process control.

Why a Subjective System?

A brief review of the author's involvement with color reproduction as a newspaper editor may best serve to demonstrate the intention and direction of this research. The newspaper had never printed process color before and personnel lacked basic skills. Immediate improvement was easy. Eventually a limit to achieving editorial and advertising goals was reached. After two years of strenuous effort the question remained, "Why can't I get what I want?"

Returning to school to study photographic, printing, and computer technologies, and ways of integrating them, revealed the limitations experienced at the newspaper were ultimately unresolved. Factors such as:

1. Quality control
2. Operator skill
3. Chance
4. Communications
5. Blurred responsibilities
6. Differences in objectives
7. Differences in perception

This realization led to an investigation of a number of assumptions underlying present technology. They are:

1. Quality control is excellent
2. High skill of all concerned
3. Knowledge of proper input and actual output
4. Visual, verbal, and system communication
5. A perfect original
6. The image may be measured successfully

While the assumption of excellent quality control may, in some cases, be dubious at best, for practical reasons it does not matter which system is employed: quality control is imperative for maximum results. This approach depends on it as well.

Skill, knowledge and communications vary from place to place, and bear directly on the validity of other assumptions. They are well-recognized sources of potential trouble and need not be reviewed here.

The investigation centered on the remaining assumptions of a perfect original, and image measurement. These assumptions were deemed particularly dangerous since they are frequently left unchallenged (life is so much easier with them). And, if there is a breakdown in skill, knowledge, or communications, the assumptions regarding the original and its measurement can be disastrous.

Measuring the Image

A meter is excellent for measuring easily identifiable, even tones such as gray scales. Images are a different matter. Four types of measurement are reviewed here:

1. Measuring neutral areas such as in shadows and highlights. This assumes there are, in fact, neutrals; and the operator will measure them, and only them. Skill and judgment are required.

2. Measuring a specific color such as flesh tones. This assumes all such colors are alike which they are not.

3. Average readings which integrate all colors. This assumes the color content will always average out to neutral which it does not.

4. Measuring a gray scale adjacent to the original. This assumes the original is perfect, which it may not be, and the operator knows which tones in the scale best represent the original, if any do.

The inherent difficulties can perhaps be demonstrated by using all four methods on the same original. It seems unlikely identical separations will result. Operator skill is needed to meter an image, even to know which approach to use. A proof is needed to determine if corrective action is necessary. Such action depends on operator skill and judgment, not new measurements of the original.

The Perfect Original

The responsibility to determine color content lies with the consumer, not the printer. In reality, translating the consumer's desires to print usually means actually determining the color result.

The practice is simple: the printer "follows copy." But, how much communication exists? The contention here is, except under ideal conditions of communication between people of considerable talent, the "perfect original" is a myth. A person often sees what is wanted and ignores what is of less interest. An editor may choose a slide for facial expression and miss a color imbalance. The eye tends to adjust to a slide.

Although color content is clearly the consumer's responsibility, people do abdicate this responsibility:

"All I want is pleasing color..."
"Look, just do the best you can..."
"Can you make it a little more red?"
"I want exactly what is in this slide..."

The last example deserves attention because:

1. The density range is most likely unmatchable.

2. The printer can not know what another person sees.

3. All colors can not be reproduced exactly due to materials problems.

4. The user of printing is buying a whole, variable run. Even if one sample did match the original "perfectly" others would not.

The practice of abdicating to the printer the responsibility for determining color content leads to uncertainty as to the consumer's intent which, directly or indirectly, often results in costly remakes.

A Systems Approach

The need to communicate visual intent for print quality control is an extremely recent development. The evolution of our language has hardly had time to recognize the problem, much less resolve it. Yule (1967) points out much of our references to color are poetic, not scientific. Nonetheless, the problem exists. From a system standpoint it would be desirable to:

1. Measure the intent of the person responsible for determining color content.

2. Use these measurements to determine separation production.

3. Establish a feedback loop for process (not press) control by measuring separation press performance against the intended result.

4. Return corrective data on press performance to separation production to adjust future separations for optimum reproduction under the actual working conditions.

Measuring Intent

A method to specify color balance is lacking. Color specification systems are limited to specific colors which appear uniform. Kodak's "cc" filters fall into such a system; but pictures do not because they consist of many such colors. Specifying color balance would seem difficult, or impossible.

Specifying color imbalance is easy. The eye is an excellent comparator. If one views a color picture under standard lighting with and without a filter, or with two filters, the eye has two versions to compare. The viewer is likely to prefer one.

The density and color of the filter giving the best, or preferred, rendition are a measure of dissatisfaction with the print's color balance. When making a photographic color print such data indicates the amount of filtration necessary to color balance the picture.

Today color prints can be made in minutes -- even just one minute. They are cheap, easy, and can be extremely repeatable. This point is stressed because the use of a color print as a subjective meter will be demonstrated. (This process can be performed without making prints, but prints do offer advantages.)

Color prints may be made directly from positives or negatives using an enlarger with dichroic filters to adjust color, a digital timer, and carefully controlled processing.

A simplified procedure would be:

1. Make a print with, or without, a meter or video analyzer.

2. Measure dissatisfaction with the print's color balance using a set of calibrated filters.

3. If dissatisfied, adjust enlarger filtration according to the filter measurement and make another print.

4. Repeat steps 2 and 3 until satisfied with the color balance and overall density.

A Null Device

Color paper has a set response to light and may be thought of as a null device. Once a satisfactory print has been made, a measure of the color adjustment necessary to compensate for the original's bias is also obtained.

The final print may now be taken as a statement of intent, not because each color is exactly as desired, but because dissatisfaction has been nulled. Any shift in color will increase dissatisfaction.

Some colors influence perception of other colors. By reaching a color balance through comparison and selection this is resolved in a way no available meter can.

The decision as to what color balance is desired is purely subjective. Since this is the art director's domain, that individual can make the final decision.

However, the facts regarding the color print's production are absolutely objective. Disregarding neutral density, only one set of conditions (i.e., exposure, filtration, magnification, emulsion, chemistry, etc.) will produce that exact print with the original provided. Such data can easily be maintained, even obtained, by inexpensive computers.

The Color Head

The dichroic head can play a very important role in this method. It commonly moves three subtractive filters in the light path in a well-calibrated manner to adjust the light's color. A yellow filter controls blue light reaching the original. Magenta controls green, and cyan controls red. A mixing chamber produces an evenly colored light to illuminate the original. Color heads are presently being built with onboard densitometers -- they are very precise.

Every meter must be calibrated to some standard. When darkroom procedures are fully monitored and standardized the original may be measured against that standard. In this sense filtration, which is the major variable, may be a measure of color imbalance (which can easily be plotted for analysis).

In a controlled procedure a tolerance of approximately .01 to .02 cc as set in the color head is common, which is somewhat tighter control than is experienced with a typical press run. A great deal can be done with such data.

Making Separations

To make separations the enlarger is set up exactly as it was when the desired print was produced. This print will be referred to as a "physical standard." For simplicity, each physical standard will be assumed to have been made to final size. Using separation filters, in addition to the subtractive filters in the color head, satisfactory exposures and processing times are determined any way desirable and recorded. The resultant separations are run on press and random press samples are saved for later use.

Assuming the first press run was generally satisfactory, separations from a different original are to be made. A physical standard is produced with standard processing from the new original. For sake of example, if the first physical standard was exposed at some f/stop for ten seconds, then while balancing the second physical standard the exposure will be adjusted with the lens so it too is ten seconds.

Differences between the originals have now been nulled with the color head and lens. The second separation set is now made using the same exposure and development times as the first set of separations.

By maintaining a constant exposure, reciprocity failure is eliminated. In practice it may be easier to adjust exposure with neutral density in the color head rather than with the lens. Adjustments for magnification and conversions from one material to another may be made in a similar manner.

Making Masks

When making masks with set exposure times, as is often done, a thin original will overexpose the mask and a dense original will underexpose it. Either can alter color correction and tone reproduction. While detectable with a check on mask number and density range, the operator still faces a remake if he chooses to correct it.

With this method, mask exposure is also based on the measurement of the physical standard. Each kind of mask receives precisely the exposure intended because the original has been nulled. In this manner all separations and masks of a given type share the same characteristics.

Important shifts in original density are software detectable and different aimpoints can be determined as experience dictates. This will become clearer when the approach to optimization is explained.

As with the separations, there are no remakes unless due to mechanical failure or human error.

Completing the Loop

A number of jobs are run, again taking samples since variability during each run and between runs may be expected. The samples are measured against their respective physical standards to determine average deviation from intended color balance and density. While it is possible to make these measurements with a device, it is at least as valid for people to measure dissatisfaction with calibrated filters. This appears particularly valid if the same person responsible for determining the color content makes the measurement. However, any person with normal vision could make the comparison.

When treated statistically these measurements are a good estimate of density. This is important because we now have a common response variable for the entire system. Color density can now be used to:

1. State color imbalance of the original.

2. Control the making of separations.

3. Measure dissatisfaction with the result.

4. Since the system may be examined statistically it is now possible to feed corrective data from press performance of the separations directly back into the mechanism making separations, the color head.

The color reproduction system used to print the separations is not likely to be perfect. Perhaps, when the press operator pulled a press sheet which looked good he did not know whether, or not, it represented the average product.

Therefore, the first set of separations possibly was not perfect. Subsequent separations would have the same problems because in nulling them to the subjective desire of the user, they are also objectively balanced to each other. This is a distinct advantage; they may be treated as a class.

For example, if the average reproduction measures cyan, calculations will indicate a change in the direction of red (opposite of cyan). If prior to making separations this adjustment to the filter settings of new physical standards is made, future separations will perform better to match the user's intent on press.

Any residual error can be detected and corrected in the same manner on the next attempt to optimize.

Optimization

Eventually, no worthwhile, statistically significant change in the separations will be determined to be necessary. At this point the system is optimized for color balance and printing density.

The optimization approach is a natural computer application. Separations may be optimized to a particular printing condition; or a number of optimizations for various printing conditions, or types of copy, etc. may be maintained. It is merely a question of data base. The only requirements are: sufficient data for significance are accumulated before making aimpoint changes; and, advance knowledge of how a job will be printed.

Further Analysis of Output

Being optimized does not determine anything about other printing qualities such as contrast, color correction, etc. It does offer a valuable diagnostic at this point: which samples of the optimized runs represent the average press output may now be determined.

It is important to bear in mind that it is dissatisfaction that is being measured. If the separations are optimized dissatisfaction approaches zero. That means the buyer is satisfied with the average color balance and overall density. The printer may now select actual samples of the average product from the optimized runs because they are those samples which most closely match the physical standard.

These samples may now be examined for common printing characteristics, some of which the printer may wish to correct using existing technology. Doing so might upset the optimization, but continued sampling would detect such a change and adjust for it. Sampling can also adjust for process drift if it affects color.

The printer may optimize two or more levels of the same factor for paired comparisons between balanced, representative results. Multiple optimizations would allow a newspaper to offer editorial rapid color production. Concurrently, advertising could have a more marketable, quality-first approach. The work to bring about an optimization need not be done at the printing plant, but may be performed at a later date in a remote, or centralized office.

Mass Media

There are two mass media not yet converted to full color: newspapers and radio. Newspaper publishers, for many reasons, have not been encouraged to retrain their personnel, or hire people with color skills.

The battle for advertising acceptance of newspaper color may have to be won with editorial color. Yet a news photographer must work under adverse conditions and quality often suffers. 35mm format makes viewing more difficult.

A key objective of this research was to enable people without high color skill or technical sophistication to control the process. The initial testing was designed to consider the problems of newspapers in general, and particularly those just beginning color work.

Simulating a Color Press

Initial testing of the process and software concepts utilized a simulation of color press dynamics. To simulate a press one must decide what a press does. The conclusion reached was that it must do just three things:

1. Handle materials.

2. Playback the original's color.

3. Produce visual noise.

The test operator could handle materials. A proof could playback the original. Noise? A press is supposed to reproduce color correctly; however, the various renditions normally produced during a press run suggest visual noise is a major, though unheralded, press function. Proofs are not made to produce visual noise.

Thus, noise was identified as the component that had to be supplied by the simulation. The intention was to demonstrate this method could optimize reproductions despite variability.

If presses ran by themselves random noise would do. A degree of randomness must exist, but there are operator and system learning to consider. The simulation employed two levels of operator learning: the first was for intentional process changes, the second for random changes.

The simulation "ran" 100 copies of the product (each copy being a set of calculated deviations for the process colors which were used statistically). The simulation also selected eight sets of data at random and stored these values for playback during the test run.

Because color variability was being simulated the actual samples were made on photographic paper which was easily controlled with filtration. After placing the data supplied by the simulation into the color head, each separation was exposed in register through the appropriate tricolor filter. This had the effect of altering the exposure through each separation filter.

Eight samples for each run with an unknown degree of visual noise resulted. An intentionally poor color balance (unknown to the operator) was used as a starting point.

The samples were measured with filters against their physical standards to determine the degree of dissatisfaction. The accuracy of the procedure was checked once by having two people measure the same set. The individual values varied considerably, but their average discrepancy for each color in that run was approximately .01 estimated density, which is negligible.

When statistically significant corrective data were entered into the separation production phase an improvement in subsequent color resulted. It was concluded the process optimized color reproduction with a recognizable improvement without intervention.

One test series was made with continuous tone separations of low contrast. The second series was made with halftone separations of high contrast (no flash). The use of a low quality starting point was, as mentioned, intentional.

Press Tests

A second series of tests was performed with an offset newspaper press. Secrecy requirements severely limited testing but some results were obtained. Color negatives were used under working conditions. To demonstrate speed, masks were designed to color-correct and allow separations to be made on resin-coated, panchromatic paper which was then processed by machine in 55 seconds.

The continuous tone, positive separations were then fed into the normal production stream. The halftones were shot with identical exposures and ganged where possible. Zero-angle screening was used. Processing was essentially the same as used for pages. Levels of skill were variable but typical of the industry. Every attempt was made to leave decision-making in the hands of newspaper personnel, including screening.

Color proofs showed uniform resemblance to the physical standards. Press samples showed greater variability but were judged to be well balanced (although a small error did exist). Tone reproduction was considered to be in greater need of modification, although only modest changes were indicated. The principal changes were made in screening aimpoints. Proofs demonstrated the improvement. However, the test had to end at this point.

Type of Output

This optimizational method may be used with whatever separation/reproduction process is desired from dye transfer to scanners. A few suggestions for scanner operation arise from this research. A scanner illuminates the orignal in order to read it. Introducing filters into the light path before it reaches the original, or substituting the light from a color head to illuminate the original could null the original prior to reading. This could reduce demands on scanner set up but might introduce other considerations. It is also possible to calculate equivalent adjustments to effectively null the original.

Scanners do have color video units for balancing the original. There is no reason why such a device could not be used to complete the loop, thus serving as a physical standard, although consideration should be given to lighting when comparing press samples with a light-emitting tube. Conceivably, the press samples could be scanned and compared visually, or electronically, to the originally determined "video physical standard."

Conclusion

The process works as intended. The only "complaint" was the process gets boring. The fun is concentrated in determining what is desired. A computer handles all calculations; the operator simply tells the computer what changes are desired, and it handles conversions and optimizations.

It is by no means unreasonable to expect the entire lab function to be influenced, or controlled by a computer so that people lacking color skills can be assured of getting what they want.

Literature Cited

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