What's on the horizon for web offset color measurement and control?

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Abstract

This paper describes a three phase plan for the research and development of a color control product at Quad Tech. Each of the phases are described in terms of functionality and difficult engineering problems.

1. Our research gameplan

1.1 The hurdles

Three years ago, when we first started seriously looking at a color control product, we experimented with putting various sensors on press. We found that we could track color changes with an off-the-shelf video camera.

Our natural tendency (as engineers) would have been to connect to the ink key motors and start controlling the ink keys. In all likelihood, we would have failed, because we would have been attempting to clear several hurdles at the same time.

The first hurdle is the accuracy of the camera. A standard video camera can produce accurate density information only if one fully understands the way that its data has been corrupted, and either corrects the limitations, or works around them. A system with empirical fudge factors is doomed to require constant tweaking.

The second hurdle is a quantitative understanding of the way a press works. Any color control algorithm must implicitly make some assumptions about how the press will respond to a change in ink key settings. The better the control algorithm can predict what a change in ink key setting will do, the better the system will work.

The third hurdle is the hurdle that all engineers must deal with. In engineering, nothing works quite right on the first attempt.

Our prototype of an ink key control system would probably fail to work when we first plug it in. Human nature being what it is, we would assume that the video camera was producing accurate numbers, and assume that the press was behaving exactly like the model in our heads. The software engineers would attribute the errors to electrical hardware bugs, the electrical engineers would blame a mechanical tolerance problem, and the mechanical engineers would, of course, blame the programmers. In all likelihood, all the engineers would be wrong, and unnecessary Band-Aids would be added to the fixtures, the electrical hardware, and the software.

Instead, we chose to take smaller bites so that we could hurdle one problem at a time.

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1.2 Phased development

1.2.1 Phase 1 - On-line color measurement.

On-line color measurement is the simplest product that still has utility. The potential market is not large, but the learning has been worth the effort. We have gained experience building a real color sensor on press, and we have been forced to make sure that we have accurate measurements. Much research has gone into getting accurate color from a video camera. At this point in time, we have two prototypes in operation. There is a team of 16 currently making this into a product.

1.2.2 Phase 2 - Closed loop automated color control, using colorbar.

This is expected to be a successful product. Beyond adding quality, the color control system will save money by reducing waste. At this date (8/21/96) our research is in full swing. We have made a variety of measurements on running presses. There is one operational press which we have outfitted so that we can determine current ink key settings and optical densities from the convenience of our desks. Computer models have been built and tested against real data. We have completed our second test of control algorithms.

1.2.3 Phase 3 - Color measurement and control in the work.

Color bars just keep getting smaller. Currently a short cutoff press allows only a width of 1.5 mm. According to work we have done [Seymour, '96, GCA], only 1.1 mm of this is actually useable. Colorbars can't get narrower than 1.5 mm and still be meaningful. Additionally, using colorbars for quality assurance begs the question, does having good colorbars mean that the work will look good? What is needed is a system which measures the color of the work.

2. On-line color measurement

2.1 What good is color measurement?

For those who may have been living in a cave I repeat the litany of why color measurement is a good thing:

> Statistical process control leads to process improvement.
>
> Measurement of color leads to a reduction of operator subjectivity.
>
> Improvement of consistency: within the run, from one shift to the next, between different presses....
>
> There is a record of the quality of the color through out the run. Essential in "makegoods".
>
> Provides a means for matching between presses when it is impractical to share press OK sheets.

2.2 *Choice of a video camera instead of a traditional densitometer*

2.2.1 Measuring color patches

Most densitometers measure the reflectance of light from a small area. There is only a single sensor (for each color range). This sensor will report the light reflected from whatever it happens to be pointing at. As web speeds increase, and color patch sizes decrease, it becomes increasingly difficult to ensure that the sensor is reliably positioned directly over the color patch when it takes a sample.

If a video camera is used as the sensor, a quarter of a million color samples are taken in an instant. With a picture of the web in memory, the computer can decide which pixels of the image belong to which patches, and which pixels are from elsewhere. In this way, the requirement for positioning accuracy changes from about 0.1 mm with a point sensor to perhaps 10 millimeters with a video densitometer.

2.2.2 Measuring in the work

Since a video camera is capable of measuring color at hundreds of thousands of points at the same time, it is the logical choice for an “in the work” color measurement system. It is capable of delivering measurements at many points at the same time, and it is immune to the problems of “where to measure”. It can report an overall color match for the whole image, or for any irregular shape within the image.

2.2.3 Downside

On the downside, video cameras were not designed to deliver accurate color measurements. Much research has been done in our research group to understand these shortcomings and correct for them. The result is an accurate measurement of the right point [Seymour, ‘95].

Video densitometry 101

As a first pass, the conversion from video frame grabber numbers to density includes the following:

> Location of the color patch, and determination of its boundary.
>
> Correcting the data for an arbitrary offset.
>
> Correcting the data for an arbitrary gain which depends on the position in the image.
>
> Averaging the pixels within the patch.
>
> Computing the logarithm.

These steps are well understood, and many of the individual techniques have been described elsewhere [Pratt, Simomaa, Mumzhiu et al, Spratlin et al, Nemeth et al, and Malmqvist et al].

Advanced understanding of building a video densitometer

Our team has spent on the order of 20 man years pushing video densitometry beyond this first pass understanding to a science. We have avoided adding fudge factors, and have always sought to understand why, rather than pushing to "just get it to work". As a result, there are at least four separate effects which we have documented, and included in the design. These effects are: scattered light, nonlinearity, goniophotometric error, and color transformation.

Scattered light correction

Just as the brightness and color surrounding a patch will change the eye's perception of the patch's color, the area around a patch will also effect the camera's perception of the color [Nemeth and Wang]. In particular, a large area of white paper will reduce the apparent density of all the patches in the field of view, reducing a 2.0D patch to perhaps as low as 1.5D. This is the effect of scattered light. How much light scatters into a patch depends on how large the bright area is, how bright this area is, and how close this area is to the patch.

The simple approach to scattered light correction is to "calibrate it out". That is to say, if the camera reads a 1.83 patch as 1.48, then all the subsequent readings are multiplied by 1.83 divided by 1.48. This approach is fruitless, since the calibration factor will depend on the background.

A second approach is closer to the mark in that it realizes the cause of inaccurate density. In this method some fraction of the average intensity of the entire image is subtracted from the reflectance readings, to account for the scattered light [Birgemeir]. The method fails in that it assumes that each pixel in the image has an equal effect on the light scattered to a given patch.

The more scientific approach to correcting for scattered light is to determine the point spread function [Dainty and Shaw], and deconvolve this from the image [Pratt]. Unfortunately, point spread functions are generally quite difficult to determine. This point spread function is extremely difficult to determine since it has extremely small amplitude and very broad coverage. Furthermore, deconvolution is a relatively compute-intensive process. We have avoided both of these problems by using an approximation to the point spread function. The shape and amplitude of this function is easier to determine, and the particular approximation lends itself to very efficient computation of the deconvolution.

Nonlinearity correction

The electronics of off-the-shelf video cameras and the frame grabbers are not generally linear enough for our purposes. Figure 1 shows the error in density due to the system nonlinearity. Here it is seen that the errors are insignificant below 0.5D, but that the errors are as large as 0.15D at densities near 2.0D. Similar nonlinearities have been reported [Deeg].

This system nonlinearity has been modeled by analysis of the circuits to develop the transfer functions. The transfer functions have been verified by measuring a calibrated light source with our system. Implementation of the correction is most efficiently performed as a look-up table.

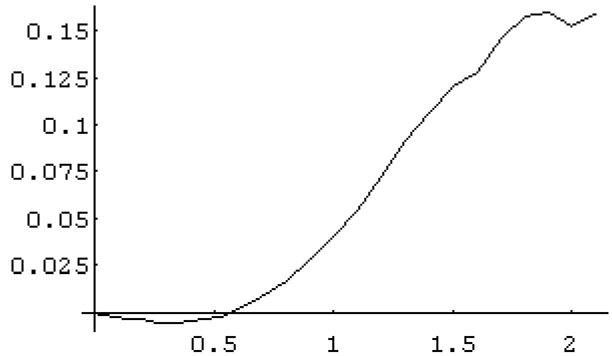

Figure 1 - Density error due to system nonlinearity

Goniophotometric error

It is well known that densitometers with different geometries (angles of illumination and detection) will not necessarily agree in measurements, and the amount of disagreement will depend a great deal on characteristics of the sample.

What is not as well appreciated is how large a change in optical density can be made by varying the angles by a few degrees. [Seymour, '96, TAGA] Figure 2 shows how the angles of illumination and detection change with the position in the field of view. The system must be designed to minimize this effect.

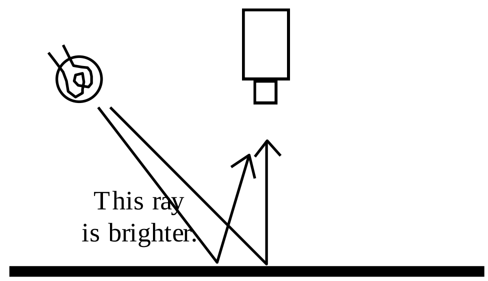

Figure 2 - the goniophotometric effect

Color transformation

The spectral response of a commercially available video camera comes close to the specified responses for Status T densities, but there is some error introduced in the density. Figure 3 compares the spectral response of the red channel from a typical video camera, and the requirements for a Status T cyan density measurement. A typical plot of the reflectance of cyan ink is overlaid for convenience.

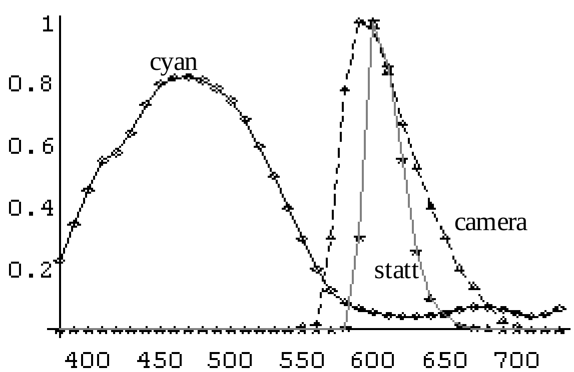

Figure 3 - Comparison of spectra of cyan ink, spectral response of video camera's red channel, and Status T requirements

From the plot, we see that the video camera and Status T peak at nearly the same wavelength, but that the Status T filter is narrower than the video camera. If cyan ink had completely flat response of the range of the video camera, this would not be a problem. The problem comes in that the reflectance of cyan is decreasing in the region of 560 to 580 nanometers, where the video camera is seeing it, but Status T does not. The result is that the video camera sees a slightly higher average reflectance (lower density) than does a Status T densitometer. In this particular case, the video camera's computed density reads about 0.1D low.

We have modeled the error introduced and collected significant data to validate the model. A simple parabolic equation has shown to provide adequate correction.

2.2.4 Summary

With color bars, the video camera allows for smaller patches, with some assurance that the proper area be measured. In the work, the video camera provides a means for answering the question, where to measure?

2.3 Can you really run to the numbers?

In theory, if all the processes in a print job are under control, getting a good color bar (with the correct solid ink density, dot gain, print contrast and trap) is all that is needed for the work to look good. How does this hold in practice?

In practice, one fly in the ointment is the ad copy. Most of the copy is properly scanned and separated. When RIP'ed and printed, it looks good. However, since ad copy is coming from so many different sources, it is hard to guarantee that the whole process is under control.

The next fly in the ointment is that the process is not necessarily in control. A common problem is that the proof may have been made with a dot gain of 22% to 28% (historically accurate), whereas a new press might run in the 15% to 18% range. Tough to get a match here!

Even assuming everything is "in control", there still needs to be some tweaking within a narrow range, for example, to get fleshtones to look good, or to come closer to an out-of-gamut color.

2.4 Some typical customers for the numbers

#1 - technical catalog. This customer has control over all the pictures, and the picture quality is not critical to selling their product. Money is saved by not requiring a proof. This is a good application of printing by the numbers.

#2 - news weekly. The time required for generating and OK-ing a proof can be a bottleneck to getting the weekly out. While the editorial picture quality is not extremely critical, the picture quality for ads unfortunately is. This is a moderately good application for printing by the numbers.

3. Closed loop automated color control, using colorbar

3.1 What is the payback?

Makeready provides printers the biggest opportunity for savings. With automation of register control, ribbon control, pagination, etc., the lion's share of makeready time is taken up getting the color in. As average press run lengths continue to shrink, makeready time is becoming a larger portion of the budget.

Ink key preset is another makeready time saver, provided that the preset system does not add another step to the process. For this reason, a plate scanner preset system has marginal payback. An ink key preset system which operates on a *digital* rendition of the plate, however, does not require an operator to load plates. The digital plate scan becomes part of the normal digital workflow and is largely transparent to the user.

Having an on-line color control system to adjust the ink keys is a benefit in two ways: 1) the on-line system is capable of grabbing a signature and adjusting the keys faster than any pressman ever could, and 2) it frees the pressman to make other adjustments, such as tension, and register fit.

It is our intention to initially offer a system which will control the ink keys. It will be assumed that there is a competent operator to adjust the ink/water balance. Our system will monitor dot gain and print contrast as an aid for adjusting water.

3.2 How to get this payback?

3.2.1 Meeting makeready goals

Having identified makeready as the key opportunity for payback on a closed loop color control system, what requirements does this put on the system? Clearly, bringing up the color quickly is important. This can be accomplished in one of two ways: either by using a closed loop system which performs iterations very quickly or by developing a model which can accurately preset the ink keys in one shot.

One of the key limiting factors for the speed of a closed-loop system is the response time of the press. Once an inking level change is made, it takes several hundred impressions for the ink levels on the paper to settle in to the new level [MacPhee '95 and Chou et al '96]. For areas of low coverage, the number of impressions will be even longer.

If we assume that the color control system must wait 1,000 impressions until the print is in register, and if we set out with the ambitious goal of reaching target densities in 2,000 impressions, the color control system has about three shots to bring in the color. This is a physical limitation which applies regardless of how fast the control system samples.

Equally important, then, is an algorithm which can determine preset ink key settings by analyzing the digital rendition of the plate. An accurate preset will require less iterations from the control algorithm.

Compared to the makeready requirements, the requirements during the run are considerably less critical. The press changes during the run which we want the color control system to react to are generally fairly slow.

3.2.2 The changing characteristics of the press

One of the stumbling blocks to automated color control is the fact that the characteristics of the press change. It would be nice if the press could be calibrated when the color control system is installed, and the calibration would “stick”. The reality is, however, that many of the operating parameters of the press can change dramatically.

One example of such a change is that the “zero point” of the ink key (that is, the voltage which is read from the ink key when the ink key is fully closed) changes. This happens gradually as the ink key wears. More importantly, the pressman often needs to make mechanical adjustments to the ink keys which can drastically change this zero point.

It is also very common for ink keys to get cocked so that more ink is available at one side versus the other. Also, ink keys routinely get stuck.

The way the ink runs also depends on a number of external variables. The control system needs to understand that the color will shift as a result of an increase in press speed. Also, anyone who has worked with ink realizes that ink viscosity changes drastically with temperature, and as the ink is worked.

3.2.3 Decoupling of the keys

An ideal press (from the standpoint of an automated control system) would not have vibrator rollers, which work the ink back and forth, laterally. The control problem that this introduces is that a given ink key will influence the density of a region much wider than that key, and the density of a given ink patch will be effected by multiple keys. This interaction is the root cause of two interesting control theory problems.

The first problem is that of *multiple solutions*. From a purist standpoint there is only one setting of the ink keys which delivers optimal ink densities, but from a practical standpoint, there are many ways to set the ink keys which will give adequate densities. Since ink key 7 (to pick one ink key) has almost the same effect as ink key 8 or 6, raising key 7 and lowering key 8 and/or 6 to compensate will have limited effect on the print. The control algorithm must be smart enough to avoid wandering among all these possibilities. Any unessential movement of the ink keys will increase the variability of the color.

A second problem is that it is possible for there to be no solutions. Because of the vibrator rollers, there are jobs where the patches cannot be brought into target density. Consider the case where there is full coverage on one page, and very low coverage on the neighboring page. The keys in the full coverage page (by themselves) will provide more ink than is needed for the edge of the low coverage page. The keys in the neighboring page need to be set *below zero* to achieve the proper densities!

A pressman will compromise a bit on the edges of both pages to get the proper visual effect. This works because the human eye is insensitive to gradual changes in color. An unintelligent color control system will nervously bounce between a variety of possibilities, searching for a perfect setting which does not exist. Again, the color variability will increase due to a “dumb” control algorithm.

3.3 Closing the "big loop"

Currently the feedback from pressroom to prepress is limited to "You guys messed up." With a color measurement system, the potential exists to adjust color profiles at the platesetter to track individual presses, individual customer preferences and paper stock.

4. Color measurement and control in the work

4.1 The need for colorimetry

When color bars are used, *densitometry* makes the most sense. When we venture into the work with our video camera, *colorimetry* becomes more meaningful.

Densitometry makes a lot of sense when we have the luxury of a colorbar. When we look at a cyan patch, the most natural question is "just how *cyan* is it?" Density answers precisely this question.

If the color patches are not available, it makes more sense to consider the *color* at each point in the image. The system should also take into account the *color appearance*, that is, how the surrounding colors effect our perception of the color.

4.2 The use of a video camera

Conventional densitometers and colorimeters have locked us in a paradigm. Since these instruments measure color at a point, there is a tendency to think that an "in the work" colorimeter *should* measure color at a point. We start asking questions like, "is the car in this ad red enough?" We try to answer this by looking at one point on the car and measuring its color. Unfortunately, the one point selected is only part of the appearance of the red car. It is better to ask if all the points which make up the car are red enough.

Another problem is that almost all continuous tone images are shaded, that is, the color changes across the image. To be able to compare the red of cars in two images with a point sensor, we must assure that the same point is being measured in both images. Otherwise, we cannot tell whether the color difference is due to placement of the sensor or is due to an actual color difference.

If a video camera is used to measure color in the work, both problems can be dealt with. The computer can compare two images, point by point, to determine how close they match. It can report the degree of match over the entire image, or over the entire body of the car. It is also fairly easy for the computer to ensure that corresponding points are being measured in the two images. Techniques can be easily adapted from the literature [Sainio and Seymour].

Conclusion

This paper has described a three phase research project which is currently underway at Quad Tech, and the rationale for breaking the project into phases has been given. The first goal, that of offering an on-line color measurement system, is immanent. The second goal, automated color control, is in full swing, concurrent with the color measurement product development. The third goal is to have color measurement and control which does not require color bars, but instead uses the work. Reaching this goal is the reason we have invested in making color measurement with a video camera into a science.

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