Beyond Traditional Control -A Paradigm for Automated Color Verification

Raymond Cheydleur
X-Rite Incorporated
Grandville, Michigan USA

Kate Johnson, Dave Wolin
KDY Incorporated
Nashua, New Hampshire, USA

Abstract

The use of an all-digital work-flow, from digital camera or scanner through computer to plate or digital press, requires the adoption of a new process control concept. The increasing use of color in the production process requires an automated and objective approach to color management at every stage of the work-flow. This is most evidenced by the variety of new desktop printers, high-end proofing and final output printing options, each with unique colorants. Replicating devices with consistent color performance is one of the most critical requirements when manufacturing equipment for the creation of digital hardcopy output.

In addition to automated but otherwise conventional process control methods (machine vision, process monitoring and control, linearization) automated color measurement techniques are needed to extend process control capabilities to include inter-equipment and inter-site process verification and performance prediction. The increased need for unambiguous communication throughout the creation process gives rise to the need for objective measurement methods that fully characterize color performance at each stage of production. These methods will be at the forefront of making control of color matching transparent to the end user.

This paper will discuss the various stages of the work-flow where automated control of color processes can be implemented, and the benefits derived at each stage: Device manufacture and calibration, device color description, device to device matching, and site to site verification. Solutions will be proposed that provide the automated and objective tools to guarantee consistent color quality throughout the digital imaging process.

Introduction

Why is a new process control paradigm necessary? In recent years we have moved away from a single site production model, with skilled craftsman were in control of the entire imaging process, and all (or most) of the critical parameters. We now have distributed, automated production environments where the mix of devices changes with every job, and the rate of change is measured in months instead of years. The basic imaging processes have changed as well. In much the same way that much of traditional typographers work shifted to the desktop designer, elements of the reproduction process are changing ownership. The digital work-flow model was virtually unheard of as little as ten years ago. It is only within the past 3 years that such a model has become widespread. With new processes come a need for new process control tools and methods that address the challenges and opportunities that the new processes provide.

Process Control refers to any procedure that aids in assuring consistent, reproducible output. Calibration is the foundation for meaningful, repeatable, reliable data. This would apply to both the instrumentation and the processes they are to control. X-Rite instruments are traceable to the National Institute of Standards as well as additional standards pertaining to each industry.

Under this rather broad definition we are going to specifically address how process control and calibration are most often applied today, and what we believe defines the new paradigm in controlled reproducible output. It is important to note that under this definition traditional process control is not abandoned, but rather enhanced by new systems and processes.

The Digital Work-flow Model

The specific model that we want to address is what we call the Digital Work-flow Model. This model includes image capture (digital camera, scanning), retouching, manipulation and compositing on distributed workstations, digital proofing which includes both *soft* (monitor) and paper proofing, and final output. One of the challenges of the new Digital Work-flow is that in most facilities the change has happened gradually which has led to a blend of traditional and digital elements. In this hybrid model, traditional process controls have been maintained (if indeed they were in place at all) and new methods have not necessarily been adopted. Thus *control* has been applied to the traditional processes while the new, uncontrolled processes are branded as unstable.

The other impact of this increasing mix of technologies is that there is no longer a single vendor supplying the tools. Integration is no longer possible using a *closed-loop* approach to process control and verification. The ability to add the latest technology is critical in today's business without the loss of use of existing tools.

The ICC profile

Throughout this article you will see the phrase "attach a profile" or "create a profile". What is being referred to is the use of ICC (International Color Consortium) profile, which is a vendor neutral method of describing the color reproduction capability and intention of a given device. While the ICC standard is currently undergoing revision, we believe that in many cases the use of these profiles is a tool that can be integrated into the new process control system. For more information about the creation and design of profiles refer to the ICC documentation.[1,2,3]

Digital Capture

Digital capture today is comprised of two distinctly different processes: Digital cameras, and scanners. The digital camera is undergoing perpetual design changes and is thus defies a well-defined, state of the art process control method. Digital cameras bear little relationship to the methods of control related to traditional silver-based image capture systems. In traditional photographic methods, control can be applied by choice of film emulsion, exposure manipulation, processing manipulation and printing, each of which has its own respective method of control: Manufacturing control of the film, metering control for exposure, time and temperature control for processing, and checking the output tonal response with a photographic densitometer. These steps form the basis for the Zone System most popularized by Ansel Adams.[4] Variations of this multi-faceted approach to process control have been used by photographers in both black and white and color photography.

Digital cameras cannot take advantage of this approach. While some cameras offer a *white balance* control as a form of calibration, and may include a metering system, few if any carry information about the scene that can be used to verify the reproduction intent for the image. As the photographer gets more removed from the output process, this indication of intent becomes increasingly critical in producing satisfactory output. One new approach is to profile the response of the camera and attach the profile of this device to the images captured by the camera in order to pass on information about the reproduction nuances of the device to the next step in the work-flow. The next revolution will be the addition of devices within the cameras to automatically attach a scene information matrix that allows for additional details regarding camera profile and image rendering intent to be passed to the next step in the imaging process along with the image data.

Scanners offer more control than digital cameras. The *scene* is more controlled, the light and lens system remain relatively stable, and are easily calibrated. A self-contained system such as a scanner would seem to offer little in the way of opportunities or need for new controls. At some level this is true, however the proliferation of desktop scanners, and need to tailor images for a variety of output uses have raised new challenges.

Traditionally scanning for reproduction was based on producing CMYK scans that were purposed only for reproduction on a specific four-color press. These scanners required hand adjusted tables to transform color information from the native RGB image capture data to CMYK to provide accurate color for their target. Skilled craftsman were responsible for manually adjusting the tables for each image. Today's world is quite different. Most images are destined for multiple uses including Internet, desktop printer output, and television as well as digital or traditional printing. This requires a more comprehensive method of handling and processing scanned image data. The method applied at this stage is to scan the image in RGB and not automatically transform it to some assumed color space. Different rendering intents will require different transformations. This multiplicity requires the development of automated processes to replace the tedious task traditionally performed by skilled scanner operators of hand-crafting lookup tables. The process needs to be automated for each reproduction model, and the results need to be verifiable which requires a method of describing or profiling the behavior of the scanner.

Most scanners provide an internal calibration routine that allows the scanner to work predictably scan after scan. In combination with this calibrated scanner, software and a pre-defined, pre-measured target (such as the IT-8 shown in figure 1) can provide the tools to create and maintain a scanner profile. This same target is used by some software companies to provide a method to profile digital cameras as well.

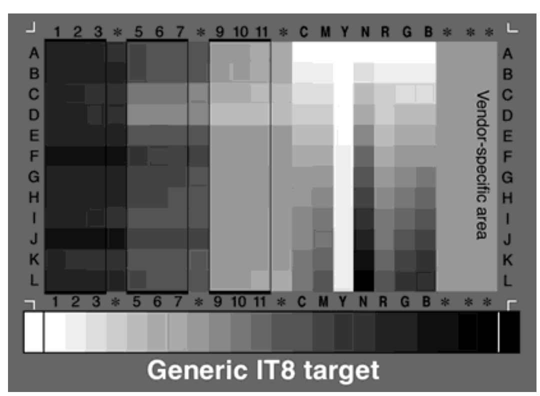

Figure 1

Calibration (traditional process control) is a critical precursor to device profiling which allows a simple, transportable method to carry information forward to the next step in the reproduction process. This information can also be used to remotely check the ongoing state of the capture device.

Digital Display

Digital display options include traditional CRT (Cathode Ray Tube) monitors, LCD (Liquid Crystal Display) and Gas Plasma display devices, with many variations within each category. The variety of manufacturers, and the variety of the computers and operating systems to which they are attached create a world where an image opened using three different computers, on three different display technologies, have almost no relationship to one another. In addition to the variety of display technologies, each major computer platform has defined a different default standard for display gamma. The rise of the Internet and large format digital photo printers has also influenced gamma choices for reproduction. Even within the relatively small world of traditional printing, different countries have defined different standards for viewing conditions. All of these new choices give rise to the need for independent calibration and profiling of displays. Having the ability to independently calibrate and profile a monitor removes many of the barriers of matching devices from different manufacturers.

Calibrating individual monitors to an independent standard gives us the assurance of a device that is reproducible over time, and it provides a method to verify the continued performance of that device. Profiling allows us to describe the particular way that a technology displays color. By combining the profile from our digital image capture device and our display device, we can now display images across various platforms in a similar manner. This also allows more flexibility in the internal work-flow within a single site since one image does not always have to go through the same workstation.

The most popular method of calibration and profiling involves the use of software and an external sensing device such as the X-Rite DTP92™ true CIE monitor colorimeter. The wide band response of the colorimeter is particularly valuable in encompassing the various spectral spikes that these display technologies typically exhibit. By calibrating and profiling the display, we have taken a significant step in providing tools and processes to automate the work-flow. We can also verify the actual state of the display by using the external measuring device and reporting back the colorimetric values in an ongoing process control check.

Digital Proofing and Printing

The digital proofing and output areas are where so much of the need for a new paradigm for process control is needed, and yet paradoxically has been the slowest to embrace the controls that will ensure that the transition is a profitable one. One of the results of the digital age and desktop computer is that everyone has become a printer, and most of us have become color printers. The need to accurately predict the quality and color of output at various stages has never been higher given that more people are involved in the process with different tools at their disposal.

One of the most widely used tools in the new work-flow is the digital proofing printer. These range from an inexpensive inkjet printer at the designer's desk to a sophisticated wide format dot for dot device capable of using actual printing stock at the print-shop. In all cases the desire is to match the final output in a predictable manner. The additional factor put in place here is the separation of content creator from the final output producer. The traditional process of press output followed the hub and spoke model. All production was done at one facility. Now in the worldwide economy the process has become the distributed production model, where many points of production are used to facilitate faster distribution at lower cost. This separation of creator and producer and the need for faster reproduction cycles have made the traditional press proof or on-press check obsolete in many cases. There is an increased need for upstream predictability in reproduction, as well as an independent verification process of the final product.

Manufacturing Prediction

A key component in increasing output predictability is the characterization and verification of the printing devices and media used in output production. If the manufacturing of the printers, inks and paper substrates can be more controlled and more automated, this allows for greater batch to batch consistency, and increased performance predictability. One process control tool that supports this new paradigm is the KDY ImageXpert™ system which is the market leader in automated image quality inspection. ImageXpert is an extensible machine vision-based product designed to allow objective image quality measurement and inspection capabilities. The core of the ImageXpert system is a powerful image analysis software package designed specifically for image quality evaluation. In addition to the software, a variety of hardware options are available to meet a variety of image quality measurement needs for use in a variety of environments. These hardware options range from simple, single camera or scanner-based systems, to very complex, multi-camera, full motion systems with integrated X-Rite color measurement capabilities.

Using this system, Xerox has been able to automate color inkjet cartridge production to both check for product acceptability and to maintain and update process control charts in real time. Many printer and paper manufacturers maintain consistency of products off the line in fully automated environments by using ImageXpert systems.

Measuring the Result

Even with increased quality in the manufacturing of digital printers and supplies, process control is needed in the day to day use of the devices. Traditionally this was performed with densitometers to calibrate and check ink densities. The new paradigm requires further information to describe the combination of ink, paper, device and environment to more completely define the color reproduction capability of a given system. This moves us beyond the simple densitometric measurements needed for process control to spectrophotometry. Densitometry defines the relative amount of light reflected or transmitted, but does not precisely define the color being measured. Spectrophotometry splits the visible spectrum into equal bands and reports the reflectance as a function of those bands (refer to figure 2) Spectral reflectivity is often called the fingerprint of the color. A spectrophotometer can also report densitometric and colorimetric values.

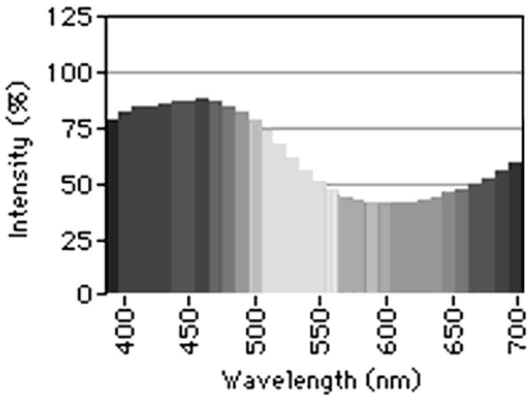

Figure 2

Spectral analysis is used in many manufacturing processes and in research and development for the creation of inks and colorants. It is only recently that this has become an affordable option at the end user level. Where basic calibration was relatively simple and inexpensive to do with a hand-held densitometer, requiring less than 100 measurements, the full description of a color reproduction process requires many more measurements and more computing horsepower to use that information. These requirements have been met with the lowered cost of desktop computers and the availability of instruments like the X-Rite DTP41™ and DTP41/T™ strip reading reflection and transmission spectrophotometers on the market. X-Rite has been a leader in producing affordable automated spectrophotometers. The DTP41 and DTP41/T are the only affordable automated strip reading reflection and transmission spectrophotometers. These devices allow the operator to read approximately 100 patches per minute and deliver that information directly to the host computer automatically. This is one of the primary tools used for end user profiling and calibration of desktop printers and proofers. If reflection readings are all that is required, X-Rite offers the fastest scanning spectrophotometer currently available in its production-oriented Spectrofiler™ system, which is capable of scanning more than 300 patches per minute. It is this increase in speed and accuracy of measurement technology along with its drop in price, which has allowed profiling of digital devices to become the norm.

Checking the Proof

The widespread democratization of spectrophotometry has also allowed the use of a simple color bar as seen in figure 3 to be used as a remote proof verification tool. Reading the strip on the proof is a 20 second procedure that will verify both the calibration of the proofing device and the quality of the color reproduction. This combination allows for off-site distributed proofing, with independent verification of each print. The data gathered from this step can also be used to verify the final reproduction step.

Figure 3

The Press

The press comes in many forms today. Digital presses allow us to go directly from the computer file to the printed sheet. Conventional presses can use computer-generated plates. Conventional presses can also be used for 6 or 8 color reproduction processes. While each of the previous examples requires a different work flow, each has a method of calibration using conventional densitometric controls, and each process has the ability to be profiled.

X-Rite offers an in-line densitometer called the DTP24™ which is used in digital presses for on-line real-time calibration control. A traditional densitometer or CCD plate reading device can be used to measure computer-generated plates. X-Rite's ATS™ auto-tracking spectrophotometer and press control software allow either off-line or direct to press console automated process control and can be combined with Spectrofiler software for press profiling. The ATS software will also generate reports that provide an ongoing record of the entire production run allowing for ongoing, accurate reporting of the entire production run, not just the results from a few sample sheets delivered when the run is complete.

With good control of the incoming supplies allowed by increased process monitoring at the manufacturing stage and increased feedback and ease of use for initial process control, profiling has become a reality for the printing press. By creating a profile of the traditional or digital press, we have put the final link in place for true color control and verification.

Conclusion

Remote Verification

All too often quality control has been assumed and not proven. We now have new calibration tools, the means to quantify each step in the work flow, and new tools to facilitate communication throughout the reproduction process. The one remaining step that we have not addressed is verification.

By including independent, calibrated data at each stage that we have outlined in previous sections, we can combine this with post-calibrated real-time measurements to provide remote verification of any step of the entire process.

Verification may take place at the manufacturing stage to carry information of the quality of the inks and papers used to guarantee their suitability for the job at hand. It may be in the designer's studio, where they can now check that the design will reproduce correctly across all of the media it is destined for. It may be at a corporation headquarters where a check of corporate identity is in place to verify that it is being rendered faithfully around the world. All of these forms of verification are possible using tools that are available today along with the implementation of automated process control and a move toward increased measurement precision. These tools give us the flexibility to choose among many options of how to create ongoing verification processes.

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