APPLICATIONS/PRACTICES PAPER

Digital Dye Transfer—Work in Progress

By Sharon Brazil and Bruce Richardson

A digital dye transfer system exploits the advantages of imbibition (IB) printing combined with digital imaging. In dye transfer printing, a digital interface makes it possible to previsualize the color gamut and provide a way to make corrections for the crossover effects and contrast of the dyes themselves, the filmstocks, and the process chemistry. The insertion of a digital link in the traditional path of the image between the camera and the print simplifies IB printing and makes it possible to process dye prints from images originated either electronically or on film. It also eliminates the use of intermediate processing steps between the camera and the matrix exposure and is fully compatible with existing post-production methods and technologies.

This paper describes Chromax's work-in-progress since an earlier report appeared in the SMPTE Journal, August 1995, p. 534.

Chromax, Inc., an R&D company, has experimented with a digital imbibition system (DIBS) that exposes matrix film through the use of digital imaging film recorders (cathode ray tube and laser) and found that it is possible to electronically, instead of optically and chemically, control color balance. A digital system permits customizing the contrast curves, crossover effects, and tonal reproduction before printing. It also provides a way of previewing images originating from film negative, positive, black-and-white separations, or digital files; and by applying look-up-tables (LUTs) algorithms to the image files, it allows previsualizing the print on a color-calibrated monitor. The digital controls allow for image manipulation, restoration, and timing in the digital domain before exposing the matrices from which dye prints are made.

Digital Dye Transfer System

The patented DIBS process (U.S. Patent No. 5,574,659) provides a printing system that enhances the inherent advantages of dye transfer. It applies recent developments in digital imaging to manipulate electronically scanned or generated images to create edited digital image files. These can then be recorded onto matrix film to control the color rendition of dye transfer prints. The DIBS system yields an extended tonal scale with blacker blacks and whiter whites, resulting in a wider dynamic range.

In digital IB printing, the positive matrix separations (cyan, magenta, and yellow) are made with a film recorder exposing the image on matrix film. After processing, the image (on the matrix film) exists in the form of a gelatin relief, consisting of a three-dimensional topography of hills and valleys, the relief (or thickness) of which is proportional to image density. During the printing procedure, the matrix film is soaked in dye, rinsed to remove surface concentrations, and brought into registered contact with a mordanted blank filmstock (mordant chemistry has already been incorporated into the film emulsion during manufacture). The dye diffuses from the matrix film into the blank to form a positive image; a colored picture appears after the third dye is transferred from the matrix film to the blank receiver.

Color Processing Methods

In the early history of printing color motion pictures, various systems offered commercial methods of processing release prints in color. In the 1930s, the Technicolor name became synonymous with "glorious color" and became the industry standard with a three-color dye transfer process. Traditional dye transfer printing was displaced in the 1970s by a mechanically simpler color-coupled process, still in use today, whereby dye precursors incorporated into the film during manufacture are put through various reactions during the development process to yield images directly within the emulsion. (Technicolor has recently revived their traditional dye transfer process, whereby three optically exposed matrices are printed onto blank film to form an image, much like lithographic printing).

Although conventional color-coupled processing has not changed appreciatively for the past few decades, post-production has moved rapidly into reliance on digital imaging, and film scanning and recording technologies. There is currently an urgent need for reconciling the control methods of digital post-production with the optical, mechanical, and chemical controls used by film laboratories. An emerging culture now demands better image quality and quantifiable standards to establish a more direct interface between post houses and labs.

Innovative technology, therefore, is critical to integrate digital and film technologies. Understandably, post-production needs a system that is technically manageable while addressing scheduling, quality, and price demands. A digital dye transfer system presents an opportunity to achieve this seamless interface. It also offers better image quality, greater technical controls, simplified processing, fewer intermediate steps, and archival permanence. What's not to like?

Comparative Advantages

The DIBS process offers distinct advantages with features and benefits not present with conventional color-coupled or traditional dye transfer processing. A digital system combines the attributes of IB printing and applies recent developments in digital image manipulation [scanned negative, positive, master separations, or computer-generated image files (CGI)] and

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electromechanical feedback systems to control the color rendition of dye transfer prints. When compared with color-coupled technology and traditional dye transfer printing, the digital system offers unique control over the dynamic range and color gamut of prints through digital color crossover corrections, nonlinearity, timing, and previewing of images. The digital link also permits designing Hurter and Driffield (H&D) curves to control the color shoulder, slope, and toe independently.

In comparison with traditional optical dye transfer printing, the advantage of a digital system is the elimination of the generational losses resulting from numerous optical steps. Digitally generated matrix separations avoid the contrast, grain, and sharpness problems in comparison with optically exposed matrices by eliminating the intermediate processing steps [intermediate positives and negatives (IPs and INs, respectively) and masking] between the camera original and the matrices. In addition, separation matrices output with a digital film recorder require only one matrix filmstock and a monochromatic source of exposure (i.e., a red-laser film recorder can be used to expose red sensitive matrix film with the cyan image separation record; a second length of red-sensitive matrix film can then be exposed with the magenta record, and a third with the yellow). By way of comparison, traditional optical dye transfer processing uses three matrix filmstocks of different spectral sensitivities exposed through corresponding separation filters of an optical printer that introduces variables that are difficult and cumbersome to control.

A digital dye system greatly simplifies processing operations, whereas both color-coupled and traditional dye transfer processes involve soundtrack negatives, optical exposures, and processing of silver halide release print filmstocks. The DIBS process, however, utilizes digital soundtrack records to expose the soundtracks onto the matrix film with the same laser film recorder used to expose the image separations. Soundtracks and images are then simultaneously printed onto nonsilver blank receiver. The use of nonsilver filmstock significantly reduces the cost of high volume release print stock, and eliminates pretransfer processing.

A digital dye transfer print is capable of a larger dynamic range (0.03 to 5.0, ~16 stops) than a color-coupled print (0.15 to 3.4, ~10 stops); the minimum density of a dye print is theoretically the density of the clear blank stock, and the maximum density can reach values of 5.0 due to the high concentrations of dye that can be transferred. Dye transfer printing offers the ability to alter the color gamut of the reproduction by using different dye combinations, an option not present in color-coupled film printing. Another advantage is the permanence of the dye print that is due, in part, to the stability of the dyes themselves, and in part to the simpler chemical processes of dye transfer that leave few residual contaminants in the print.

Test Experiments

The purpose of the tests was to demonstrate the use of digital exposing techniques before processing 35mm and 70mm dye transfer prints. Experiments were organized around the use of digitally scanned images recorded onto blue-sensitive matrix film stock with a cathode ray tube (CRT) film recorder.

Most images were shot on Kodak Ektar ISO 25 with a 35mm still camera. Rhythm & Hues Studios scanned the images, made custom LUTs, and output the 35mm matrix separations on a Management Graphics Film Recorder Cine III. The images were then reformatted to 65mm and output using an MSM 65mm multiformat camera on a Cine III recorder.

Film tests were conducted using Kodak's experimental dye transfer matrix and blank stocks on polyester base, also in use by Technicolor. Of the three matrix (red, green, and blue sensitive) filmstocks formulated for an optical process, the blue sensitive was selected for these tests because of its higher speed, which allowed CRT exposures. Because none of the film samples were available, however, in 70mm matrix and receiving blank, Chromax slit and perfed the stocks in-house (35, 65, and 70mm) from 5 and 7-in. web rolls. [During previous tests when modern film stocks were unavailable, Chromax made its own film coatings, synthesized mordants, did experimental test draw-downs of emulsion coatings, and had final test coatings done at Anitek (a division of International Paper in Binghamton, NY).

Preliminary selections of dyes were analyzed through the use of a Hewlett Packard laboratory research spectrophotometer (300 to 800 nm range with 10 nm resolution). Dyes were selected on the basis of their color purity, spectral crossover characteristics, stability, permanence, and compatibility with process chemistry and filmstocks. Step wedge exposures were used to determine the sensitivity of the film stocks and gave preliminary data for creating LUTs. Custom process chemistry involved the formulation of developers, rinses, and washes.

Final dye transfer printing was done via a mechanized laboratory system for 35mm and 70mm. The challenge in performing the prototype mechanical-chemical processing in stop-motion was similar to flight testing an F-14 in a garage, when it should have been a dynamic physics process occurring in a closed environment with continuous feedback controls. What appears at first glance to be a straightforward chemical process combined with lithographic mechanical printing is in fact more akin to applied physics dominated by close tolerances in registration, temperature, chemical interactions, and digital controls.

Operations

The Chromax test facility resembled a laboratory inspired by Jules Verne. In a multipurpose garage (used as a chemistry lab, machine shop, photo-lab/darkroom, and central processing area), specialized equipment was designed and custom built including a pneumatic film perforator and mechanized dye transfer equipment. In addition, a conventional film slitter and 35mm ultrasonic splicer were modified to accommodate multifilm formats.

The film perforator punched all 35mm and 70mm formats (including Imax). Because accurate registration was important, the perfs needed to exceed SMPTE standards with an accuracy of ±0.0002 in. cumulative error in 15 perfs. The total cumulative error was 1/10th allowed by SMPTE/ANSI Standards. (This task brought to mind a statement made by Mel Brooks, "What's the toughest thing about making film—putting in the little holes.")

With the use of a thermostatically

controlled prototype transfer board, three digitally exposed and dye-soaked matrices (cyan, magenta, and yellow dyes) were sequentially laid down on the receiving blank, thus creating a final positive image. Registration of each dyed matrix took place on full-fit pins on one edge of the film with travel pins on the opposing edge to accommodate either 35mm or 70mm. With the use of a drive system with a gear-motor driven ball-bearing lead screw, a pressurized roller carriage mechanism pressed the dye-soaked matrix into contact with the receiving blank. The dye was then absorbed or imbibed (hence the term, imbibition) onto the receiver.

Test Results

The DIBS test results demonstrated the color range a dye system can capture from subtle skin tones to dynamic saturated colors and dense blacks. The use of modern film stocks and precision machining helped maintain the consistency of transfers and accuracy in registration to resolve up to 40 line pairs/mm. In addition, the use of digitally generated matrix separations reduced the difficulties and generational effects (i.e., contrast, grain, sharpness, and multiple film stocks) in comparison with optically exposed matrices.

A variety of test images included a range of scenes under different lighting conditions that exhibited skin tones, metallic surfaces, Christmas ornaments, flowers, foliage, and starfields. Accurate color is one of the strengths of a digital dye system, including better color rendition (as evidenced by hues of pink, green, and periwinkle), plus superior color separation, clear highlights, and good shadow detail. The tests resulted in images with a wider color gamut, deep saturated colors, blacker blacks, whiter whites, and greater dynamic range (0.03 to 4.8, ~16 stops) than conventional processing.

There were limitations, however, in using the blue-sensitive matrix and CRT recorder. The blue-sensitive matrix proved disappointing because of its limited resolution and pronounced grain. (The blue-sensitive matrix was designed for the yellow record, where resolution and grain are not critical.) Although it was thought that the red- and green-sensitive matrix filmstocks would have superior resolution and finer grain, the blue sensitive was selected due to its higher ISO, which allowed exposures with a CRT. The chief problems encountered with the CRT, in addition to the long exposure time and limited throughput, were phosphor bloom and image drift between separations. Consequently, color fringing was frequently apparent around objects due to drift and bloom.

In certain images, the contrast was too high, and highlights appeared washed out due to inappropriate curves in the LUTs. The solution, however, is to create new LUTs that extend the dynamic range, and redesign the H&D curve to digitally control the shoulder, slope, and toe independently, thereby increasing the gamma in the shoulder, maintaining the slope gamma, while decreasing the gamma in the toe. This will produce greater separation in very dense areas of the image, create natural-looking contrast in midrange, and distinguish subtleties in the highlights.

Work-in-Progress

The present objective is to improve the resolution, grain, and contrast characteristics of test prints with higher resolution filmstocks and a laser film recorder to eliminate the bloom and drift problems apparent in previous CRT exposures. Current experiments are being conducted to test the slower red- and green-sensitive matrix filmstocks (which are thought to have resolution and grain characteristics similar to intermediate film stock). In addition, new software and LUTs are being created for producing 70mm digital dye transfer test prints.

In the near future, the development of a 70mm laser recorder will permit a

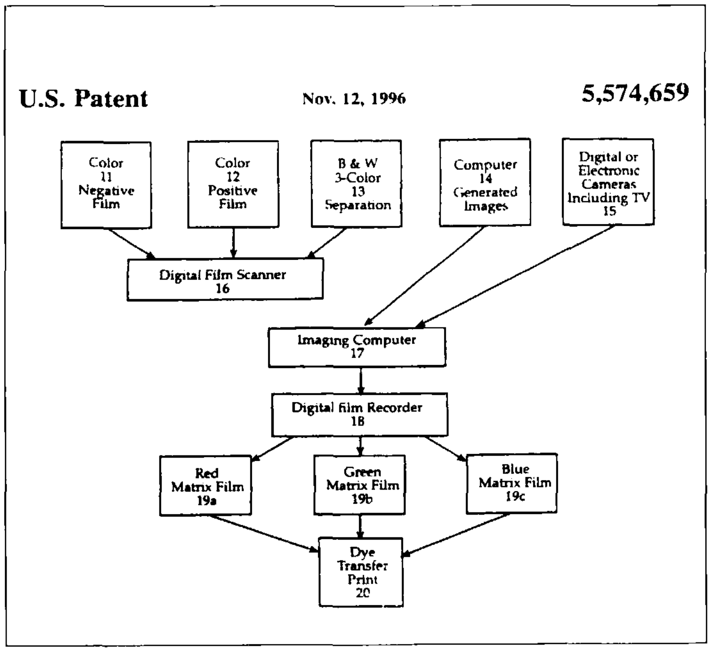

Figure 1. Conventional methods of processing motion picture release prints.

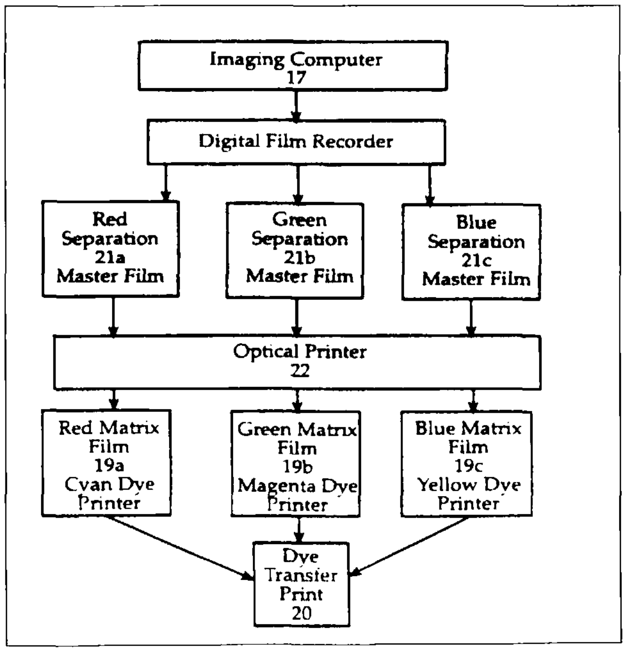

Figure 2. Chromax DIBS method of processing motion picture release prints.

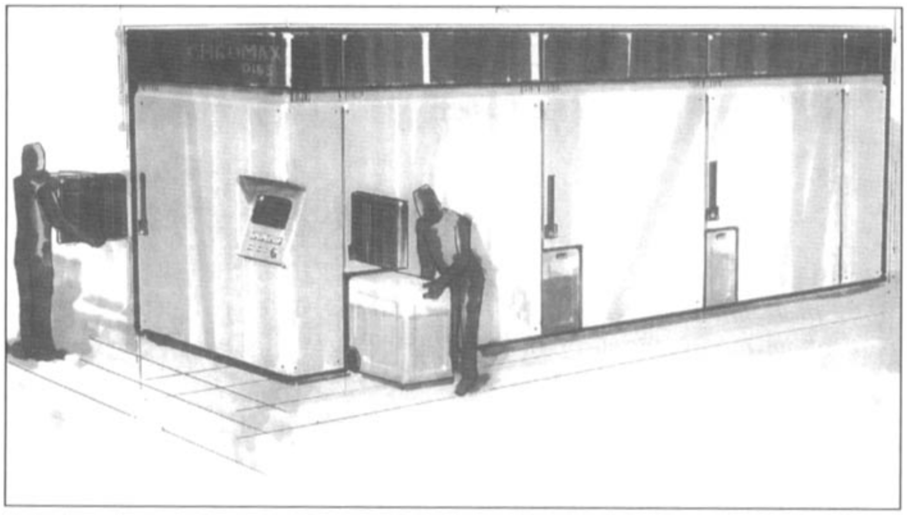

Figure 3. Chromax digital imbibition system (DIBS) transfer printer.

direct method of matrix film exposure (Fig. 1) and thereby eliminate intermediate and optical steps. Because a 70mm laser recorder is not yet commercially available, however, current tests are being conducted around an indirect method (Fig. 2) through the use of a 35mm digital (laser) film recorder to expose VistaVision separation negatives. An optical printer is then used for format conversion to print-up from the 35mm VistaVision separations to 70mm 5 perf and Imax formats on matrix film.

Through analysis of the data from the initial test prints, information is then applied to the next iteration of LUTs. Successive laser exposures and optical printings are repeated until achieving the desired H&D curves. The completed LUTs are then used to expose a new series of test images.

The final step will be the development of an automated commercial printing system (Fig. 3) designed as a compact (8 x 10 x 35 ft), modular, self-contained unit that is single-story construction, easy to install, and capable of exploiting the advantages of new developments in technology. It will utilize noncontact registration alignment techniques, currently in use for integrated-circuit manufacturing, continuous feedback systems such as realtime microdensitometry to control flow-thru chemistry adjustments with nontoxic chemistry, and reduced water consumption. The entire printing process will take place in a self-contained clean-room environment provided by the system's enclosure.

Summary

A digital dye transfer system combines the qualities of traditional dye transfer printing with modern digital technology. Chromax has demonstrated, through laboratory testing, that it is technically feasible to perform dye transfer printing that allows the digital manipulation of images before printing. Digital imaging creates an output capability for electronically originated images that bypasses any intermediate stage. Because the digital correction is different in range and nature than chemical and optical corrections traditionally available, it is possible to have more finely adjusted variables in a dye printing system than ever before.

The DIBS system offers distinct advantages with features and benefits not present with conventional color-coupled or traditional dye transfer processing. Digital dye prints are capable of more brilliant saturated colors, wider dynamic range (0.03 to 5.0, ~16 stops), blacker blacks, whiter whites, greater shadow detail, and clearer highlights than conventional release prints. In comparison with traditional dye transfer printing, the advantage of a digital system is the elimination of generational losses from numerous optical steps. Digitally generated matrix separations avoid increased contrast, grain, and loss of sharpness in comparison with optically exposed matrices by eliminating the intermediate processing steps (IPs, INs, masks), thus shortening the path between the camera and release prints.

A digital dye system offers the capability to produce a release print of higher quality and permanence. Although the hallmark of a digital dye print is accurate tonal reproduction and archival stability, expanded color choices also increase the visual impact for both animation and CGI images. In addition to improved visual effects for theatrical and special venues exhibition, the advantage of a digital dye print's expanded image information can include

- Better video/digital versatile disk (DVD) color duplication.
- Enhanced high-definition television (HDTV) broadcasting.
- A permanent color record for film libraries.

A digital IB system proposes a solution for the quest of the all-digital studio to create the future and preserve the past.

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