COLOR SCANNERS - A TUTORIAL BIBLIOGRAPHY

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Abstract

Color scanner development over the past ten years is reviewed. Some references are also made to earlier sources that are relevant to recent developments. The trends in scanner design, from analog to digital signal processing, and rotary to flatbed scanning are discussed. The increasing use of color video displays as aids for scanner setup are also reviewed. Patents as well as articles from the scientific and technical press are included in the bibliography.

Introduction

The use of the electronic color scanner for producing color separations has accelerated in recent years to the point where scanners are by far the dominant method that is used for color separation production. Bruno (1984) reports that the U.S. scanner population increased from 320 in 1977 to 1,700 in 1984. He also estimated that the total share of scanner-produced color separations from 20% to about 70 - 75% over this period.

Vast changes have taken place in color scanner technology since the first scanners were tested in the late 1930's. Technological progress in color scanner design has been periodically documented by bibliographies or review articles. The last major tutorial bibliography on color scanners was published by Preucil in 1975. Other bibliographies have been published by Watford College of Technology (Moore, 1971), the Graphic Arts Technical Foundation (Lloyd and Attenbaugh, 1980), and the T & E Center of the Rochester Institute of Technology (Clark and Cost, 1984).

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Several general review articles on color scanning have been published. Some of the major reviews include those by Allen (1958), Anon (1964), Spangler (1971), Anon (1972), Ynostroza (1975), Edmonson (1979), Goodacre (1979), Thaxton (1980), Chapman (1981), Goodstein (1982), and Swarbrick (1982). The Eastman Kodak Company published (Anon, 1981) a 24-page booklet that was exclusively devoted to color scanners. Durbin (1985) has published comprehensive color separation scanner comparison charts for the major equipment available in the U.S.

The literature of the past ten years can be grouped under the headings of: input devices; computational aspects; video image display; and, output devices. Where it is relevant, reference will be made to pre-1975 articles.

Scanner Input Technology

The most significant development in scanner input technology in recent years has been the reintroduction of the flatbed scanning technique. One of the first color scanners, the Interchemical machine (Hardy and Wurzburg, 1948) utilized the flatbed configuration. The scanning chase reciprocated under the scanning source. The Hell Colorgraph (Kyte, 1960) and the Hell Colour Klischograph (Hell, 1957) also utilized the same line-by-line approach to capturing image data. The major problem with this approach is that scanning time is very slow. The scan input (and output) table has to be constantly accelerated, slowed, and the travel direction reversed. The mechanically inefficient flatbed scanner could not compete with the rotary drum scanner which, by the mid 1970's, was the exclusive input scanning technique.

The other "flatbed" input technique was the cathode ray tube (CRT) employed by the Crosfield Scanatron (Allen, 1956). This approach solved the speed problem but there were other, more serious problems. The input to the scanner had to be color separation negatives that had been made to final size. The output of the Scanatron was corrected halftone positives. The reliability, resolution, and consistency of CRTs, that have been used in color scanners, has generally not been high enough.

The new approach to flatbed color scanning was introduced by Eikonix in 1982 (Lianza, 1981; Anon, 1983-84; Masia, 1984). This was followed in 1984 by the Scitex "Satlite" portable input scanning device that is intended for scanning 35mm originals for newspapers or newsmagazines (Seybold, 1984). ImagiTex are also developing a flatbed color scanner that is based on the same approach.

The key difference between the old and new flatbed scanning approaches concerns the image recording mechanism. Prior to the Eikonix machine, microscope optics, filters, dichroic mirrors, prisms, and a photomultipliers were employed on scanners to capture image detail on a line-by-line basis. The Eikonix, Scitex, and ImagiTex machines utilize solid state arrays called charge couple devices (CCDs) to capture image data. The CCDs (Inoue, et al., 1985; Wilson, 1983; Mir, 1983; Hirschberg, 1985) usually contain 2048 light receptors in a linear array. Some machines achieve a 4096 array by using two CCDs and appropriate optical elements.

The input picture resolution on a CCD scanner depends on the sampling frequency. The original is imaged through a lens on to the CCD. The sampling frequency is adjusted by the position of the lens. For example, it is possible to either image the width of a 4" x 5" transparency across the whole 4096 element CCD, or to adjust the focus so that only one half of the width is imaged on one pass, while the rest is imaged on the second pass. The required input resolution will depend on the degree of enlargement or reduction for the reproduction. One method that is employed to create the red, green, and blue signals when using a CCD scanner, is to make three sequential passes of the image, changing the filter each time.

Other recent innovations in scanner input technology includes the use by Eikonix of red, green, and blue filters that are designed to simulate the response of the human eye. The advantage with this approach is that the scanner will "see" colors the same as the human observer, thus eliminating the need for complex selective color connection controls.

The Royal Zenith Linoscan scanner has eliminated the problem of maintaining photomultiplier balance between the three color separation channels. One photomultiplier is used for the color signals. The input drum makes three positionally equal revolutions while a "chopper" wheel rotates to allow sequential red, green, and blue signals with each respective revolution.

Eikonix have suggested the use of a direct scanning digital copy camera for providing input signals to a color scanner (Masia and Gregory, 1985). Three to five minute scan times limit this device to the scanning of stationary objects.

Other developments in input scanning technology concern improvements in productivity. These include Crosfield Data Systems' method for feeding and transporting originals to a scanner (Sheck, et al., 1984; Rossini, 1984); Dainippon Screen's method of capturing two lines of scanned information with every revolution (Sakamoto, 1985); and several approaches to automated scanner setup. These latter approaches include the automatic white-point setting of Hell (Hoffrichter and Knop, 1979) and Crosfield (Pugsley and Preston, 1984), and the automatic black-point selection system of Hell (Holfrichter and Knop, 1978). Dainippon Screen have developed a method of automatically switching calibration settings to correspond to the requirements of different originals that are being scanned together on the same drum (Ueda, 1977). Dainippon Screen's other advances in automated scanner setup include: a device that utilizes a decision-tree approach to classify originals in terms of highlight and shadow points, tone reproduction, color correction, and other factors (Yamada, 1985a); a setup condition recorder that enables the precise identification of image position with respect to tonal and color requirements (Ueda, et al., 1984); a method of automatically determining color control conditions, such as color correction and tone reproduction (Ueda, et al., 1983); and, a method of filing setup data by reading such data in the form of graphs (Yamada, 1985b). A final method of improving productivity by reducing input scan time was developed by Xerox (Kermisch, et al., 1978). Their method utilized a laser light source for input scanning.

The quality of input scan information was addressed by Hell (Juergensen, 1984) with the development of a light pick-up device that supresses the effect of image defects such as scratches. Eichler, et al. (1983) have developed a scanning device that utilizes a colorimetric response input system.

A method for covering up image defects via the use of fluoroscent paint and a special aperture and threshold circuit was developed by Crosfield (Pugsley, 1975a). The combination of several images on a scanner through the use of a special masking drum has been invented by Hell (Keller and Knop, 1981).

Computational Aspects of Scanning

The preferred approach to color correction by scanner manufacturers has been to undertake "global" correction for the ink-paper-press conditions. That is, individual colors in the original are not corrected one-by-one; rather, compensation for the defects of the printing manufacturing conditions and materials are made with the assumption that the subsequent color separations will be corrected for all colors within the original. The original Murray and Morse scanner (Murray and Morse, 1941) utilized this principle as did virtually every other commercially available scanner up to the early 1970s.

The primary advantage to the "global" color correction approach is that an analog computer can be constructed that facilitates rapid scanning. The correction is autoatically computed (based on the settings of a series of variable resistors) at the speed it takes for the electrical signal to travel from the input photomultiplier to the output exposing source. As electricity travels at close to the speed of light, the limitations on scanner speed have to do more with film exposure requirements and mechanical stability concerns rather than computational speed.

Point-by-Point color correction was first attempted on the other pioneering scanner, the Hardy and Wurzbrug machine. Circuits were devised (Hardy and Dench, 1948) to solve the Neugebauer equations for all points in the original subject. The speed of this machine was limited by how fast the computer could solve the equations. This fact, and others, helped ensure that this type of scanner never did reach the commercial development stage.

A new approach to color correction was introduced by Korman (1971) in the early 1970s. Using a small general-purpose digital computer, Korman developed a look-up table approach to color imaging. He stored in computer memory a series of tristimulus values together with the corresponding yellow, magenta, cyan, and black dot values that, when printed, would create the tristimulus values. When the original was scanned, the memory would be searched to find, for a given point on the original, the corresponding tristimulus values. When the values matched, the computer would print out the accompanying values of yellow, magenta, cyan, and black. Interpolation was used for in between colors. For a variety of reasons, this scanner did not reach the stage of commercial development.

The first successful scanner that was partially based on the principle of digital computation was developed by Crosfield (Pugsley, 1975b, 1976; Wood, 1977). The color correction circuits took the digital form of previously described (Dobouney, 1971) analog circuits. These correction circuits, together with "limit" information from the original, are used to generate a look-up table. The original is wrapped around a cylinder and scanned point-by-point as the drum rotates at high speed. The subsequent analog signals are converted to digital form. The look-up tables are searched to find the matching red, green, and blue filter values and, thus, to determine the halftone values for the printing colors. This approach was modified (Pugsley, 1982) by sending the scan signals individually through an initial look-up table before going through the color look-up table. The initial look-up table helps to reduce the potential loss in picture detail that could be experienced with discrete-step look-up tables.

The first all-digital scanner was the Eikonix machine that has been previously described (Masia, 1984). The image is initially digitized through the CCD input device. When the scanner is ready to relate input values to YMCK values, a look-up table is used to locate the RGB inputs. The look-up table is generated from a printed test target of 200 color patches (Rudomen, 1985). The table is completed by using the Neugebauer equations to calculate many more color values and their corresponding reference points. It reportedly takes a powerful minicomputer over twelve hours to generate the look-up table.

The Dainippon Screen Company (Yamada, 1982a, 1983; Atoji and Yamada, 1982) have also taken the look-up table approach to color identification. Their computational approach utilized Clapper's quadratic equations (Clapper, 1961). Sakamoto (1977, 1978, & 1981) has developed interpolation techniques in order to reduce the memory requirements and improve the efficiency of the look-up table method.

The problem of interpolation between colors in a look-up table has also been addressed by Crosfield (Franklin, 1982) and the R.R. Donnelley & Sons Company (Clarke, et al, 1984; Clark and Boyer, 1984).

One of the problems with analog circuits for color correction is that it is difficult to individually correct one color without "crossover" correction being applied to other colors. Keller (1975) has developed a method of reducing this problem.

The primary focus of color correction circuits has been the correction for the printing conditions, specifically the unwanted absorptions of the inks. In order to refine the unwanted ink absorption correction, "selective" color correction adjustments are usually provided on analog scanners. The filters, photomultipliers, light source, and other optical path elements contribute to the scanner's response to color being different to that of the human eye (Bellis and Moon, 1981), thus necessitating further color correction, normally applied through the "selective" color controls. This process is often slow and cumbersome. Methods for improving the efficiency of adjusting the selective controls have been developed by Hell (Knop, 1978; Gast, et al, 1980; Wellendorf, 1982).

A recent computational feature that has been added to most scanners is the ability to perform gray component replacement corrections. This is the process where black ink replaces a combined equivalent of yellow, magenta, and cyan inks. Hell (Gaulke and Jung, 1984; Jung, 1985) have published details of their method.

The final area of development in the computational aspect of scanning concerns unsharp masking (USM). Some problems with prior approaches to this procedure included:

USM was only effective in the direction of scanning; the "boost" of the black and white areas at the edge of detail tended to be uneven; and, the same degree of USM is not always desirable across the picture area. These problems of USM have been addressed, respectively, by Dainippon Screen (Yamada, 1982b), Crosfield (Aughton, 1980), and Hell (Knop, 1977).

Video Image Display

In cases where customer corrections must be incorpoated in color separations, it is usual to make a color proof from the completed separations in order to judge how well the scanner adjustments produced the desired results. This proof is also used to judge the efficiency of the non-customer related color corrections. The major problems with this strategy are that it is very time consuming, is wasteful of materials, and, where the proof and printing conditions do not match, the proof will not necessarily provide a reliable guide to color fidelity.

The first method of "electronic proofing" was developed by Hazeltine Corp. (Reeber and St. John, 1974). With their machine, completed color separations were imaged on a color CRT. The color display could be adjusted to correspond with individual ink-paper-press color gamuts. Individual tonal adjustment of the individual separation images was also possible and a method was provided for relating the adjustments back to the color separation system. This method reduced the time required for viewing completed color separation films, eliminated the use of proofing materials, and provided a reasonable degree of color fidelity. Further development of this equipment allowed the recording and subsequent viewing of magnetically stored color separation images (St. John and Zagardo, 1982).

Similar "color printing process simulators" have been developed by Dai Nippon Printing Co. (Horiguchi, et al., 1982; Horiguchi and Sasaoka, 1983; Horiguchi, et al., 1983) and by Toppan Printing Co. (Mikami, 1984; Seki and Kato, 1976).

The primary disadvantage of the color printing process simulators is that color separation films first have to be produced before a video image can be created. Several approaches have been developed for accepting red, green, and blue image signals instead of the four-color process separations as input to color video systems. Toppan Printing developed a method (Seki and Kato, 1981) of using a color video camera to capture image color data in order to aid scanner setup. A similar device has been developed by Dai Nippon Insatsu Kabushiki Kubota (Tanaka and Kubota, 1983). Other non-video scanner setup devices have been reviewed by Southworth (1985).

Color printing simulation systems that interface directly with color scanners have been developed by Crosfield (Pugsley, 1977a), Dainippon Screen (Yamada, 1981), and Hell (Klopsch, 1980a, 1980b, 1981). The advantage of such devices is that they allow for the inspection of the electronic proof before any films have been generated. Also, manipulation of picture controls is duplicated in the scanning circuits so that the final films will incorporate the results of the color and tonal adjustments that were made to the video display. Methods of individual color adjustment within the displayed image have also been developed by Crosfield (Pugsley, 1985), Dainippon Screen (Yamada et al., 1984), and Hell (Jung, 1981; Gast et al., 1983; Klie and Wellendorf, 1984a, 1984b; and, Hennig, et al., 1985). An adjustable video display is an integral part of the Eikonix scanner. Masia, et al. (1985) has reported good color fidelity when video displays are properly used.

Other related advances in the application of color video technology to color scanning includes work by the Massachusetts Institute of Technology (Schreiber, 1985). Their system generates a video simulation of the printed color separations. Red, green, and blue scanner signals are used as input to the system. A method of capturing signals from television systems or videotape and directly preparing color separation films was developed by Dai Nippon Printing Co. and Ikegami Tushinki Co. (Fujita, et al., 1984).

It is usually desirable to have a hard copy proof of video display images for customer approval. One method of accomplishing this is to generate color separation films and to make a proof from them via normal techniques. If, however, corrections have to be made, then new separations must be generated. Hell (Jung, et al., 1985) have developed a method of producing a hard copy photographic proof from a digital data base so that it simulates the appearance of the video display, which, in turn, simulates the final printed reproduction.

Scanner Output Technology

The major developments in output technology in the past ten years have concerned electronic halftone screening technique. The use of this technology, particularly when a laser beam is employed as the exposing source, has enabled reductions in scanning time, the elimination of contact screens, and has increased the development latitude of the exposed films.

One of the first commercial electronic screening systems was introduced by Printing Developments Incorporated (Moe, et al., 1976). The PDI system utilized a laser as the exposing source and allowed for changes in dot size, shape, position, and angle. It was claimed (Chapman, 1974) that this method produced an apparent increase in resolution, for the same screen ruling, than could be obtained by other means.

The Hell system of electronic screening (Gast, 1974) also utilized a laser for exposure. A laser beam was split into six beams which were used to expose one half of a dot per revolution of the scanner. Special screen angles had to be used for this method. Later developments (Gall, 1981) allowed the use of any screen angle. Another development by Hell was a CRT halftone imaging system (Keller, et al., 1978).

Crosfield's electronic screening system also utilized a laser for exposure (Pugsley, 1977b; Aughton, 1978a, 1978b). One feature of the Crosfield method is that it has the ability to generate dots that have a lower fringe or border density than they have in the center (Hammes, 1983). This feature allows the subsequent dots to be chemically dot etched.

The Dainippon Screen electronic screening method (Yoshimoto and Tsuda, 1984) can be used to expose continuous tone images as well as halftone images. The Scitex electronic screening system (Rosenfeld, 1982, 1984) also utilizes a laser and is capable of generating halftones at any angle.

The other major advances in output technology concern the placement of the picture image on the film. Crosfield have developed a technique for exposing all four color separations at the same time on one piece of film (Pugsley, 1975c). Dainippon Screen have made developments that allow the independent positioning of multiple input copy at the output stage (Yamada, 1984). Other Dainippon advances include the ability to generate more than one separation from multiple originals on to the same piece of film (Tsuda, 1982; Yamada, 1982c); and, Yamada and Nakade, 1982).

Further developments in output technology concern the tint laying device of Dainippon Screen (Ikuta and Atoji, 1985), the "outline image" technique of Dainippon Screen (Saitou, 1984), and a method of efficiently using memory when generating multiple-image output that has been developed by International Electronic Photo Process Laboratory Co. (Nasu, 1981).

Summary

The changes in color scanner technology within the past ten years have been almost as great as all the recorded development of scanners prior to 1975. The advances have included: the introduction of multi-sensor, solid-state image detection devices; the subsequent use of flat-bed scanning configuration; the successful use of digital computing techniques for color correction; the use of color video displays to facilitate scanner setup; the ability to retouch and change individual color areas independently of other colors; the use of electronic screening techniques; and, the capability of producing multiple-image output with precise image placement.

The merger with color electronic image assembly systems seems to be the next stage in scanner evolution. Indeed, this has already happened to a large degree. Scanners increasingly take a modular from consisting of an input station, an image processing terminal, an output station, and the necessary storage disks. The image processing terminal is used for color retouching, but it can, in many cases, be used for electronic image assembly. The image processing station will become the focal point for future scanning and assembly operations. The input station may be replaced by a digital camera and the output station will either image plates directly or generate photographic images through the use of digital techniques. The next ten years of scanner development may rival the last ten years.

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