REQUIREMENTS for a DIGITAL STUDIO CAMERA

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Abstract: Recent advances in the field of high-resolution color still electronic imaging -- particularly the development of the self-scanned photodiode and charged coupled device arrays -- now makes possible the advent of an all electronic studio camera. Such a device can be used in place of a standard view camera for input of digital color image data directly to an electronic color separating system; thus, eliminating the costly and time-consuming steps of photographing a scene, processing the film, and scanning the resulting transparency. The resolution, spectral sensitivity, and speed requirements of an electronic studio camera are reviewed. Images generated with an early version of such a system are presented, and its limitations are discussed.

Functional Description of the Digital Studio Camera

The digital studio camera described in this paper is similar in form to a conventional view camera. It consists of a lens mounted on its stage, a bellows, and an image plane. Instead of placing a photographic emulsion at the image plane, however, a high-resolution solid state photo-electric sensor is used. The sensor is electrically connected to a set of support electronics. This device samples the image plane into many picture elements, or pixels, and assigns a digital number to each that depends on

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the image plane irradiance at that point. These digital values are passed directly to a modern Color Electronic Prepress System (CEPPS) where a digital image is formed, stored, processed, and written as a set of halftone separation films.

A flow chart of a typical process that might be followed between photographic studio and printed product is shown in Figure 1.

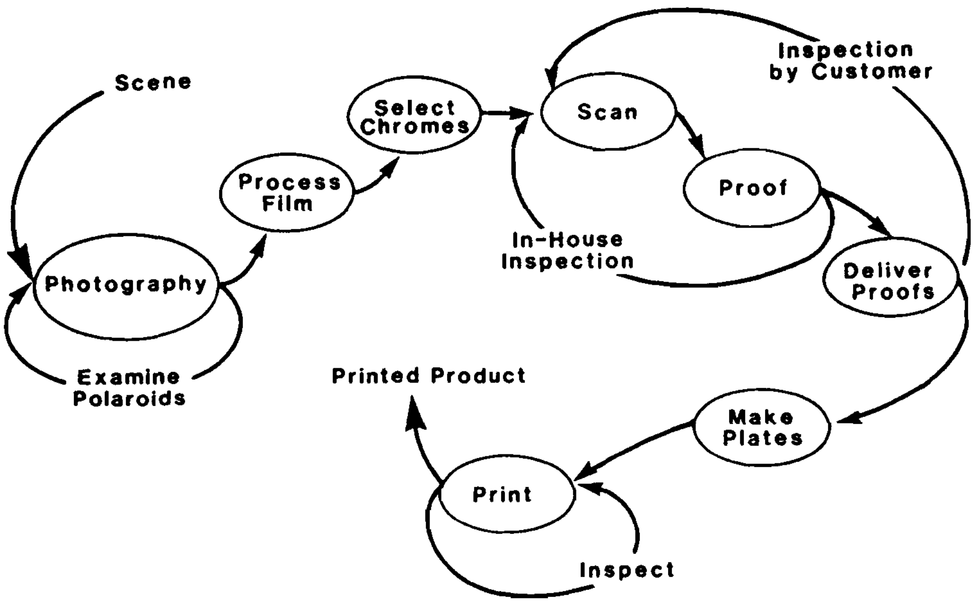

Figure 1. Process flow for conventional production.

The operations within the circular flows are iterative and may be repeated several times before the required result is obtained. Expensive materials are used at each of these time and labor intensive steps, and significant capital investments are utilized. The process is seen to be even more difficult when it is realized that the Inspection/Selection process may be performed by persons other than the photographer in another location, and that the proof of the scanned result may be inspected in yet another location by yet another person. Feedback to the scanner operator may take hours, or even days as the user of the separations may be in a location remote from the scanner.

Figure 2 shows the process flow for an equivalent process when the digital studio camera is employed.

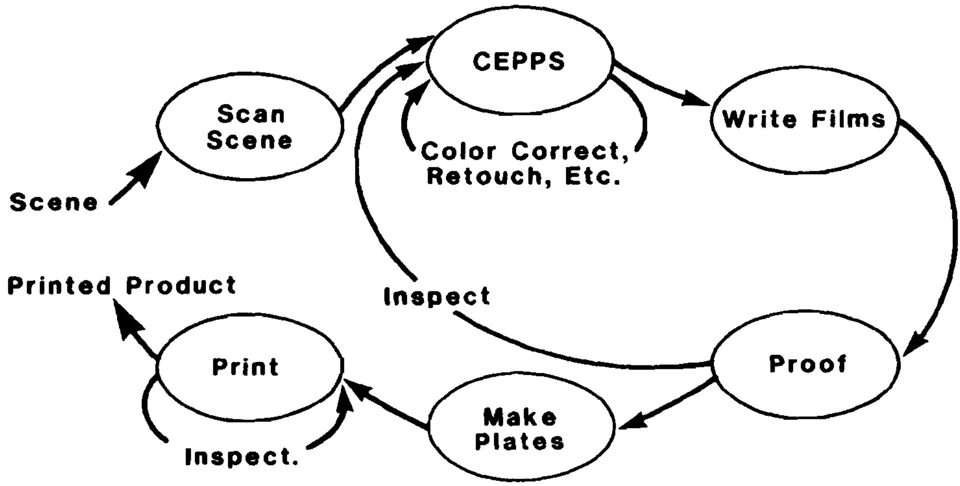

Figure 2. Process flow for production using digital studio camera.

In this process the scene is scanned, using the digital studio camera, directly into a color electronic prepress system (CEPPS). The CEPPS supports various digital image manipulation functions including color and tone adjustments, unsharp masking, retouching, sizing, etc. All of these functions are monitored in real time on the soft copy (CRT) display on the operator's console. The photographer, the operator of the CEPPS, and the buyer of the separations can all be present during this process and, within a matter of minutes, have access to the electronic version of the color image. The buyer can then approve the required electronic color corrections and retouching before a set of separation films is produced. Conventional prepress proofs are then made in the usual fashion, directly from the separation films, and these are delivered shortly after.

Requirements

The performance characteristics that must be specified in order to design a digital camera include the sample density, dynamic range, sensitivity, time to scan, and spectral response functions.

Modern electronic film writing equipment requires at least 250 digital samples per linear inch of output in order to insure high-quality reproduction. For an eight inch page, a total of 2,000 pixels are necessary, and this is independent of the size of the input copy or object. It would be better, of course, if more samples were available, but for most reproductions at single page or smaller sizes, 2,000 pixels across one dimension of the copy are sufficient.

Scenes typical of those encountered in outdoor pictorial photography have dynamic range between 1.45 and 2.80 log units (Hunt, 1975, p. 214), or up to 640:1 in linear units. For dramatic effect, however, and to ensure transparencies of full density range, photographers often light studio scenes in ways that produce ranges that are far greater. Since the final print will be produced with a density range of between 1.4 and 1.9 at most (Yule, 1967, Chapter 7), transparencies of such high contrast make the scanning process more difficult. The photographer must fill this entire range because the transparency is his end product; even though it is only an intermediate step in the entire photomechanical reproduction process.

In the case of the digital studio camera, the electronic image can be considered intermediate since the user cannot view it directly. Instead, only a representation of this image is available in the form of a picture displayed as a soft copy proof on the CRT monitor. It is up to the system designer to modify the image for display by appropriate manipulations of the digital image data. For this reason the density range of the reflection print can be filled using virtually any desired tonal transfer function; even if the scene is illuminated to produce a log luminance range of 2.0 or less. A system with a log exposure range of 2.0, or a dynamic range of about 100:1 is probably sufficient for most studio situations. If the primary application of the digital camera is to the scanning of large relatively flat artwork with no dark shadows, then the dynamic range requirement is even less.

Spectral sensitivity requirements for color separating systems have been discussed by Yule (Yule, 1967, Chapter 6) and others. Ideally, the system should be fitted with a set of color matching functions (cmf's) so that images can be measured accurately and with no metameric effects. Usually compromises are made, and masking requirements are reduced by taking advantage of the fact that photographic copy does not have arbitrary spectral reflectance and transmittance characteristics. In the case of the digital studio camera, however, it is expected that objects of arbitrary spectral reflectance will be scanned, so it is important that the spectral sensitivities of the system be as close as possible to cmf's. If the data processing system resident in the CEPPS is capable of performing a projective transformation of the color image data with arbitrary coefficients, then the cmf's used in the camera can be related to any convenient set of primaries.

In order to replace the conventional photographic system under the widest variety of circumstances, the electronic studio camera must be able to scan the entire scene in a matter of a few tens of milliseconds when the scene is illuminated at a level of 500 to 1000 footcandles. Scan times on this order allow the recording of objects moving with moderate velocities. On the other hand, many scenes include only static objects, and in these cases scan times of many seconds, or even a few minutes, may be acceptable. For example, images used in advertising often show only the product surrounded by inanimate objects. Scenes of this type are a significant portion of the population of studio photography intended for reproduction.

Closely related to the required scan time is the absolute sensitivity of the detectors employed. In the case of the photographic emulsion, all of the effective detectors (silver halide grains) are exposed simultaneously so that the total exposure time is simply the time required to expose any one detector. In the case of the electronic scanner, however, not all of the detectors are exposed in parallel. The total scan time, TST for the digital studio camera is given by equation 1.

$$TST = M \times IT \times (N / P). \qquad 1$$

In equation 1, M is the number of color channels that form the image, IT is the integration, or exposure time for a single pixel, N is the total number of pixels in the full picture, and P is the number of detectors that integrate in parallel.

Linear Array Imaging Characteristics

Linear array imaging devices differ significantly from film systems in their response functions. Color transparency materials are typically designed with an average gradient of about 1.5 and a gamma of about 2.0. With a density range of about 3.0, a useful log exposure range of about 1.6 log units results. Although this is slightly less than that of many typical scenes, gamma is kept high in order to increase the color saturation of the transparency. The dynamic range of the chrome is limited by the finite D_{max} and D_{min} of the material and even over the straight line portion of the D-Log H curve the film does not have a linear response function*.

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*Since the D-Log H curve is a log-log representation of the system response, its straight line portion defines a range of exposures over which

Solid state multi-element array sensing devices use silicon photodiodes as the basic sensing elements (Hopwood, 1980). These are typically used in a photo-resistive mode by maintaining a bias voltage across the device and sensing the total number of charges passing through the sensor in a fixed exposure, or integration time. As a result, the sensors behave linearly in their response to image plane irradiance up to a maximum, or saturation level. At the low end, the response of the detector is limited, not by any finite minimum threshold in sensitivity as is the case with photographic emulsions, but rather by the noise characteristics of the detector and the supporting electronics. Devices with peak signal to RMS noise ratios of over 5000:1 have been demonstrated. If a minimum detectable signal is that for which the signal-to-noise ratio is about six to one, then a useful dynamic range of about 833:1 (2.9 log units) results using this technology; this is in excess of that available with film systems.

Typical response characteristic curves over a 1000:1 exposure range are shown in Figure 3 for a silicon photodiode array and for Ektachrome film. In the figure the abscissa, or response axis represents $\log(S/S_{sat})$ for the electronic detector and $\log(t)$ for the photographic system. S and S_{sat} are the signal and saturation signal respectively for the electronic detector, and t is the photopic transmittance of the film system.

It would be erroneous to think that scenes with log luminance range of nearly 3.0 units can be faithfully recorded with such systems, however, because some of this range is lost due to flare in any real imaging camera. The response functions shown in Figure 3 are repeated in Figure 4, but this time with the addition of an amount of flare equal to one percent of the highlight image plane irradiance. This is a flare factor of 2.0 as defined by Jones and Condit (Nelson, 1977) for a scene with log luminance range 2.0.

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this function obeys a power law. Only if gamma has a value of -1 is a linear response indicated.

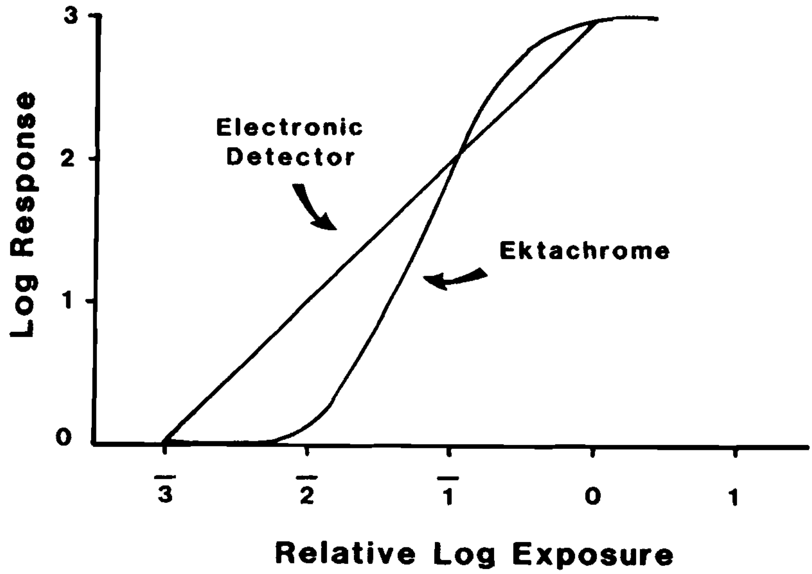

Figure 3. Response functions for film and solid state detector array systems.

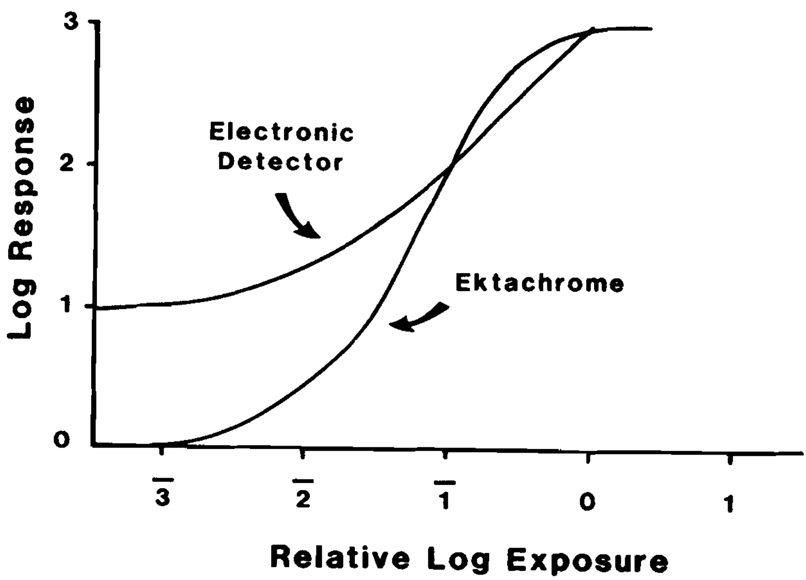

Figure 4. Response functions of Figure 3 with 1 percent flare added.

Description of the 78/99

The linear array based scanner described in this paper is based on an existing product, the 7800 series Image Digitizer manufactured by the EIKONIX Corporation. The system consists of two components: a scanning head and a set of control electronics. An interface to the host CPPES, (in this case the EIKONIX DESIGNMASTER[R] 8000), is also required.

The scanning head, or camera, is made up of a lens that forms an image of the object to be scanned, a linear photodiode array mounted on a precision stepping stage, and the required amplifiers, clocking circuits, and A/D converter. For this application a color filter wheel is also fitted to the camera so that separations can be made under host system control. The linear array is located in the image plane oriented orthogonally to the stepping axis of the array stage. In use, the array is first positioned along the upper edge of the image to be scanned, the first line of data is electronically transferred into the host system, and the array stage is translated to the next line. The operation is repeated until all of the lines of image data are collected. Color separations are formed by recording the entire image three times; once each through the red, green, and blue color separation filters that are automatically positioned in front of the lens.

The control electronics contain all of the required power supplies, the operator's control console, data conditioning circuits, and a data normalizer. This latter circuit is required to correct fixed pattern artifacts in the data. Each of the individual photodetectors behaves linearly with image plane irradiance, but with its own unique bias and gain characteristic. In other words, the signal from the k'th detector, S_k is given by equation 2 when the image plane irradiance at that point is E.

$$S_k = G_k \times E + B_k. \qquad 2$$

In equation 2, G_k and B_k are the gain and bias (responsivity and dark components) respectively for the k'th detector. If uncompensated, these terms result in patterns in scanned images that manifest themselves as highly objectionable streaks in the vertical direction. The normalizer circuit subtracts a dark current and multiplies by a gain term that is unique to each detector. The result is that the corrected output signal from each array element is the same for a uniform field at any intensity level.

In addition to the normalizer board, an input color computer (ICC) is part of the interface between the digital camera and the CEPPS. This computer does not perform any color correction, as in a conventional color scanner, but rather converts the red, green, and blue data words into the chrominance and luminance representations that are used by the CEPPS (Masia, 1984). All color corrections are made at the electronic previewing console of the host CEPPS.

In principle, the camera head may be mounted on a tripod, fitted with a view camera type ground glass viewfinder, and used to scan various three-dimensional objects or scenes. Another useful configuration of the system is as a vertical copy camera. In this mode, the scanning head is mounted with its attached lens on a vertical column. This configuration is particularly useful for scanning large reflection artwork such as paintings, posters, fabric samples, etc.

The response characteristic curve of the 7800 series image digitizer is as previously shown in Figures 3 and 4. Scan times of three to five minutes are typical when the object plane is illuminated at a level of 450 footcandles. Because of the total exposure time required, scanning of moving objects is not possible.

Image quality at least as high as that available with conventional photographic methods has been demonstrated. Figure 5 shows the Modulation Transfer Function (MTF) of Ektachrome film along with that of a linear photodiode

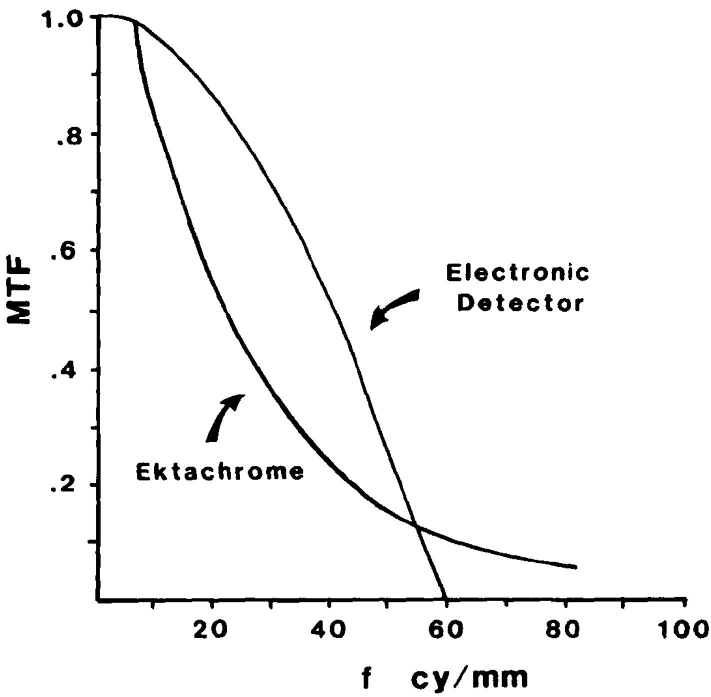

Figure 5. Modulation transfer functions of Ektachrome film and linear array with rectangular aperture.

array. It is assumed that both the size and the center to center spacing of the detectors are 15 micrometers. Note that although the cut off frequency of the film system is higher, thus indicating a higher resolving power, the mid frequency response of the array is superior to that of this particular color reversal film. This indicates an increase in image sharpness.

Future Developments

The current instrument is limited for applications in the area of direct color scanning of scenes by its speed and the number of addressable elements. The speed, in turn, is limited by the sensitivity and signal-to-noise ratio of the detector array, not any limitations on the basic clock rate of the device.

The scan time can be decreased by (a) increasing the sensitivity of the device, or (b) decreasing the noise level (thus decreasing the lowest usable signal while maintaining sufficient dynamic range). Some newer charged coupled device (CCD) image sensors show promise of improving performance in both of these areas. The overall behavior of these devices in extremely high-quality image scanning situations has not yet been fully investigated however. Scan times of a minute or less are probably achievable using this technology.

Two-dimensional scanning devices that operate at video (0.033 seconds per frame) rates are also now commercially available, but these units are limited to arrays of about 500 elements on a side. This is considered too low for high-quality graphic arts scanning applications. Even if devices of this type were manufactured at the sizes required, however, it is not clear that their extremely high speeds could be exploited due to limitations of large word length A/D converters and other low noise ancillary circuit components.

Linear detector arrays with more than 2048 (up to 4096) are now becoming commercially available. It is a relatively simple matter to use these in digital cameras similar to the one described in this paper. In fact, the Model 850 Image Digitizer uses a 4096 element CCD array. The Reticon RL-2048-H array employs sensing elements on 0.015 millimeter centers so that the entire image area is about 30 millimeters on a side, slightly larger than a 35mm camera frame. The 4096 element device from Reticon is manufactured with the same detector size so that the total image size is about 60 by 60 millimeters, nearly identical to the common six by six centimeter photographic image size. Only slightly increased camera size and scanning array stage travel are necessitated by the larger array.

Conclusions

A direct scanning digital copy camera has been demonstrated. The device, in its current form, is useful for scanning relatively flat reflection copy into a modern color electronic prepress system without the need for intermediate photographic steps. The modular design allows the scanning head to be mounted on a horizontal stand or tripod so that three-dimensional objects and scenes can be scanned as well. Three to five minute scan times limit the use of this device to the recording of stationary objects, but many scenes of practical importance can still be scanned. Some improvement in the area of total exposure time is foreseen, but times in the tens of milliseconds required for the recording of portraits and moving objects are not in the near future.

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