Scan Film: Combining the Best of Analog and Digital Imaging

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Abstract

Analog and digital image processing comprise a wide range of related features and possibilities. The objective of this paper is a comparison of both methods, where the common functionalities yield in a suggestion for the design of a simpler silverhalide film. This scan film contains only rudimentary analog image processing capabilities which can be superseded by using digital image processing resulting in an overall improved imaging system.

Introduction

An analog quantity is measured on a continuous scale while a digital quantity is measured on a discrete scale. Optical density is a typical analog quantity of the yellow, magenta, and cyan dyes in a conventional color negative film after processing, thereby being a measure of the blue, green, and red exposure information.

Photographic processing of a silverhalide film is an interesting example for analog computing: The mathematical operations during photographic processing of a color negative film consist of

- simple multiplications (i.e. amplification),
- matrix operations in the three colors, and
- some few non linear operations

in parallel(!) for the whole image.

In the past, analog computers were substituted by digital computers, resulting in systems with improved quality and new possibilities. The scope of this paper is to demonstrate that this can be equally done in silverhalide photography.

Most of the analog operations in a color negative film, except the amplification and dye forming step, can be replaced by digital image processing after scanning with a digital computer. The resulting system with a simpler silverhalide film and digital image processing capabilities has several advantages compared to a conventional film and also to "digital" sensors.

From Color Negative Film to Scan Film

The relevant processes in a color negative film are shown in figure 1. For a more complete overview of the possibilities of analog image processing in color negative film see reference [1,2].

After exposure a latent image is stored in the silverhalide crystals of the blue, green, and red sensitive layers of the film (step 1a.).

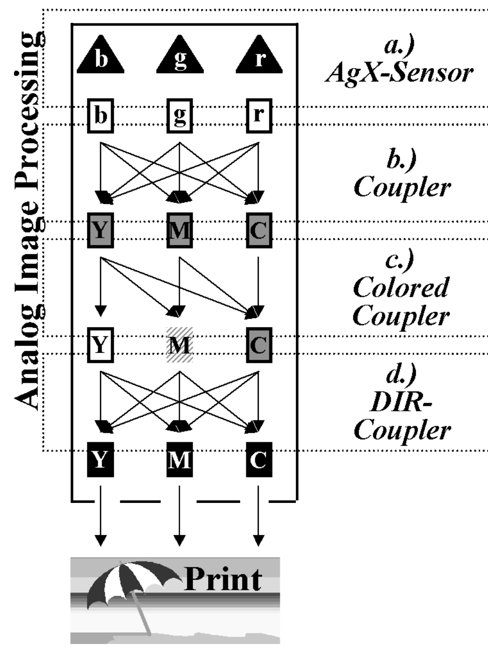

Figure 1. Analog image processing in a conventional color negative film during the photographic processing (symbols are explained in Figure 2).

Steps b.) to d.) of figure 1 take place during photographic processing where the latent image is transformed into the visually perceivable dye image. The depicted steps do not take place subsequently but rather simultaneously. The shown subsequent scheme is just for "didactic" reasons.

In step 1b.) the developer is oxidized only at the silverhalide crystals with a latent image and the oxidized developer reacts with the dye coupler to the dye. Due to unwanted absorptions of real dyes (e.g. the magenta dye does not only absorb green, but also blue and red light) the yellow, magenta, and cyan parts of the absorbtion spectra represent no longer the original blue, green, and red exposure information as indicated by the symbols with a dark gray background. Without correction the consequence is a loss of color saturation.

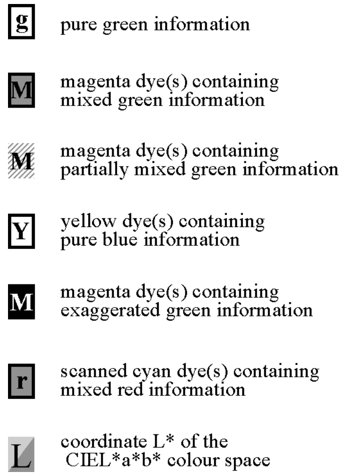

Figure 2. Used symbols and explanations.

A first correction of the mixed three color channels in a conventional color negative film is done by colored couplers,[3] which undergo a color shift from unwanted to wanted absorbtion (step 1c.). Due to exposure intensity loss only three (Y to M, Y to C, and M to C color shifts) of the six theoretical possible colored couplers are applicable. The operation 1c.) yields a yellow absorption containing the pure blue information, a magenta absorption containing the green information with false blue information. The cyan absorption contains the wanted red information mixed with false blue and green information.

In step 1d.) the color information becomes purified additionally: DIR couplers (development inhibitor releasing couplers) react with oxidized developer thereby releasing inhibitors.[4,5,6] These inhibitors diffuse through the recording material and decrease the amount of developed silver per latent image (long range interlayer effect). This mechanism leads to an improved correspondence of the three absorptions with the orignal blue, green, and red exposure informations, resulting in an image with even higher color brilliance than that of the original scene. In Figure 1 the exaggerated color informations are indicated by black symbols. In general DIR couplers have impact not only on color reproduction, but on granularity and sharpness too (short range intra layer effect).[6]

In a scan film steps 1c.) and 1d.) are completely obsolete (figure 3), just the amplification step 3a.) of silver development and the dye forming step 3b.) are sufficient. The yellow, magenta, and cyan absorption of the resulting dye image - carrying the mixed color information - are scanned by a today purchasable film scanner and are converted from analog to digital indicated by b, g, and r symbols with a dark gray backround. Now digital image processing in form of non linear algorithms without look up tables takes place (step 3c.). It has to be implemented specific to the scanner and scan film: Output is the complete reconstruction of the original color information. To gain a better quality of color information and to become independent of the output device it is useful to transform the image directly into a metric color space like CIE L*a*b*.

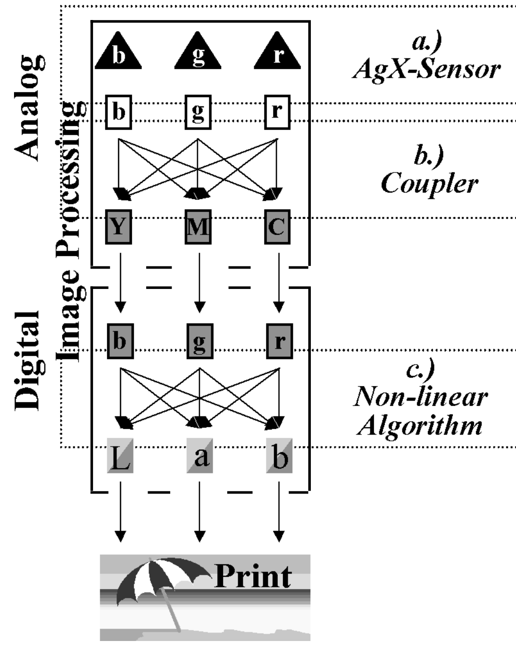

Figure 3. Separation of image processing of a scan film in an analog and a digital part.

The main advantage of the scan film compared to a conventional material is the absence of step 1c.) and 1d.). Both steps decrease sensitivity and density of the conventional color negative material. This decrease has to be compensated for by an additional laydown of silver and dye forming couplers: the benefit of analog processing leads up to 50% higher material costs. Furthermore, due to optical scattering, the higher amount of silverhalide crystals can deteriorate sharpness.

For the sake of granularity and sharpness DIR couplers should not be completely omitted.[6] In contradiction to a conventional material one has the chance of choosing DIR couplers with high intra and low inter layer effects.

An additional advantage in digital image processing is the mathematical simulation of the effect of the complete set of colored couplers. Thus in a scan film all unwanted absorptions can be corrected, while in a conventional analog film - as mentioned above - only three of six.

Comparison with Digital Cameras

Why not directly using semiconductor sensors, as silicon CCD or CMOS chips? The answer is not that easy, because both systems have advantages and disadvantages as shown in table 1. In our opinion, the most remarkable differences can be found for the noise, sensitivity, and information capacity criterion:

Noise criterion: Digital cameras have the disadvantage, that noise increases when exposure time increases. For exposure times above 1/60 second the low bits of the digital output are completely filled with noise. Due to this fact the equivalent ISO camera speed decreases with increasing exposure time.[7]

Table 1. Benchmarking of "digital" and AgX sensors (positive features with grey background).

criterion	"digital" sensor	AgX sensor
• stability of unread image	unstable pixel information	stable latent image
• availability	immediately	after chemical processing
• reuseability	multiple	one way use only
• noise	continuous sensor ▶ constant noise is integrated over exposure time	thresholding sensor ▶ noise is exposure time independent
• limitation of sensitivity	by pixel size and fill factor	crystal volume
• information capacity per frame size	low	high
• readout	in general linear ▶ measures intensity	logarithmic ▶ measures exposure
• pixel arrangement	regular ▶ aliasing problems	random ▶ good modulation transfer function
• price for high resolution	high	low

Sensitivity criterion: AgX crystals have superior sensitivity per exposed area compared to "digital" sensors based on silicon. This can be understood considering the photo effect, which depends on the atomic number (Z_{Si}=14 and Z_{Ag}=47) to the 4^{th} or 5^{th} power. Because of the already higher utilization factor of the "digital" frame area, this effect can only be compensated partially by a fill factor of 100%. To gain a sensitivity beyond the fill factor limit the only way is to increase the pixel size. A silverhalide film can take advantage of other means, e.g. chemical sensitivity improvements.

Information capacity criterion: The number of pixels—as a measure of spatial resolution—is one way to increase the information capacity of a "digital" sensor, the number of bits per pixel the other. Figure 4 shows a comparison of the information capacity between different "digital" sensors and a typical 135 color negative film (Agfa HDC 100 new); the information capacity is calculated according to [8]. The diagram shows the information capacity limit of "digital" sensors as a dashed line which can be reached only by sensors with a fill factor of 100%. To get a "digital" camera with an information capacity equal to Agfa HDC 100 new, an expensive chip and an expensive lens for the large frame size of 30x46mm^2 are necessary.

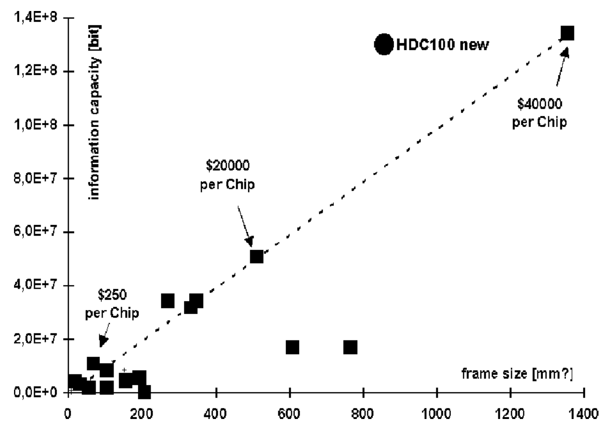

Figure 4. Comparison of information capacity vs. frame size of digital sensors (CCD and CMOS, rectangular dots) with a conventional silverhalide negative film (circular dot).

Conclusions

A silverhalide scan film in combination with digital image processing has advantages compared to conventional silverhalide color negative films and to today's digital cameras. The resulting hybrid system features

- high sensitivity,
- low noise, and
- high information capacity
- at a reasonable low price.

Due to the absence of most analog image capabilities the remaining chemical system - consisting only of the information recording, amplification, and dye forming step - is less complex and can even be designed more efficiently than conventional AgX films.

References

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