DESIGN CONSIDERATIONS FOR CONTACT SCREENS USED IN DIGITAL PROCESSING

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Abstract: A major problem in digital image processing applications is high quality halftone output. In this paper, we examine some contact screen requirements for this task. In addition we examine an alternate system which allows a laser system to make direct halftones in an analog fashion.

Introduction

In digital imaging systems, there are many factors which influence image quality. The most basic of these factors is tone reproduction. Digital systems tend to be linear and discrete. This is in sharp contrast to analog recording systems and film systems.

The standard contact screen has developed empirically to minimize tone reproduction problems in most photographic systems. The advent of electronic analog scanners has influenced screen design.

Because the screens have developed in an empirical fashion, non-standard applications often yield disappointing results. In this paper we examine the screen properties which are best suited to most digital recording applications. An optical system which exploits the coherence properties of the laser beam and allows for reshaping of the beam is also described.

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Tone Reproduction in the Camera

There are a number of excellent sources which describe the camera tone reproduction cycle in great detail.[1,2] The figures presented here will be used as a basis for comparison in the later sections.

The first issue to be examined is the positive and negative reproduction characteristics of a "hard dot" halftone system. Assuming that we had a halftone image whose large area densities were measured, and we then contact printed this halftone on a negative working media we would have a reproduction curve as in Figure 1a. The result of a positive working media would be described by the straight line of Figure 1b.

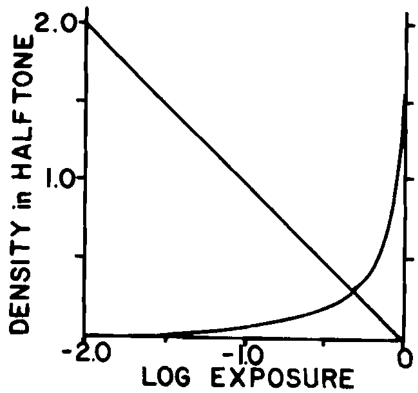

Figure 1: Positive/negative halftone characteristics
a = curved line; b = straight line

The difference between both reproductions should be clearly seen. This very basic fact has led to the development of both positive and negative contact screens.

Figure 2 is the tone reproduction cycle of a typical camera system. A four quadrant plot is used to describe the complete cycle.

Quadrant 1 is the camera curve. The camera is thought of as a black box which converts some input density to a log exposure on the film/screen combination. Quadrant 2 is the characteristic curve of the screen and film combination. This combination converts exposure to a given halftone density. Quadrant 3 describes the contact process of a halftone negative working system (as in Figure 1a). One notes that the screen/film combination is the only real variable in the process.

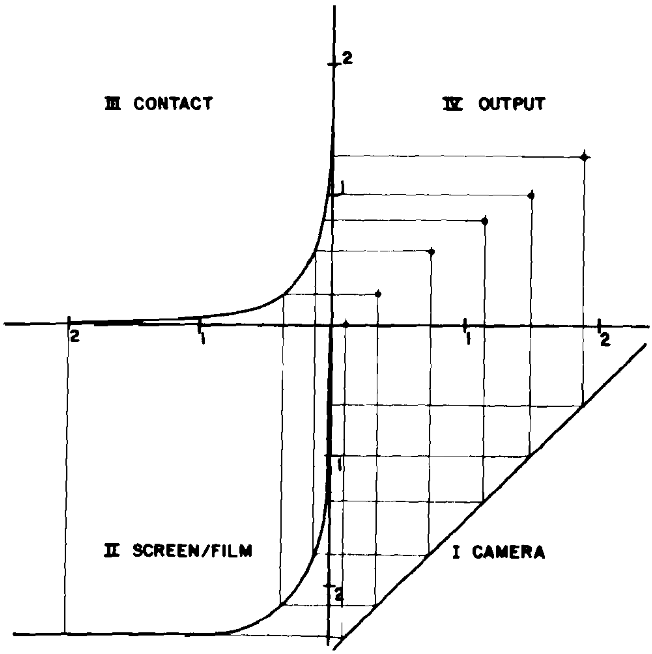

Figure 2: Camera tone reproduction

One can further influence the tone reproduction by using techniques, such as a bump or flash, but the screen is still the predominant factor in the whole cycle.

Tone Reproduction in the Scanner

The tone reproduction cycle in the scanner is given in Figure 3. Note that the only difference is in the first quadrant. When using a contact screen, the reproduction in quadrant 2 is always the same. The scanner input system can provide a wide variety of mappings by electronically altering the input transfer function. Note that nothing changes in quadrants 2 and 3. The output reproduction is vastly changed by even small changes in the input function. The greatest strength and potential pitfall of the modern scanner system is its flexibility in adjustment. Without a thorough understanding of the tone reproduction requirements, the adjustment cannot be made.

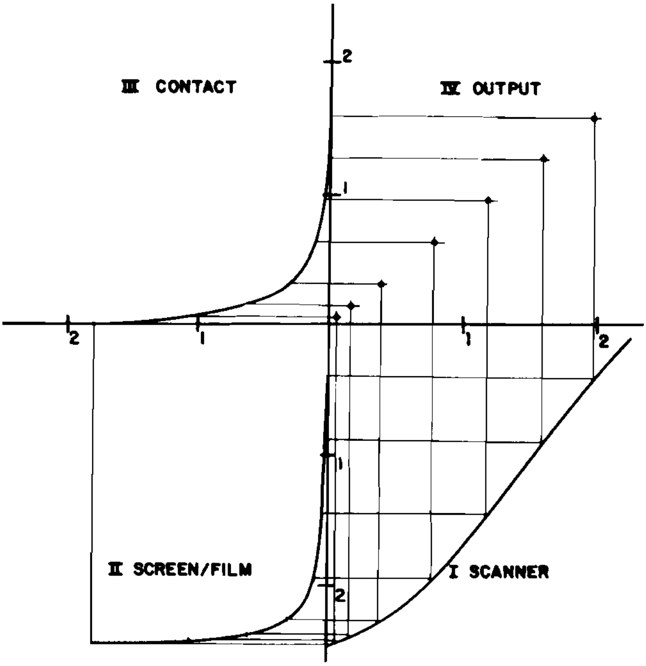

Figure 3: Scanner tone reproduction

The screen still determines the tonal characteristics of the system. In fact, the scanner is really a correction or "touch-up" device.

The Digital System

Digital systems are a blessing and a curse. The stability and precision of a digital system are beyond reproach, but the accuracy and utility of such systems are always subject to careful examination.

By definition a digital system is discrete in nature. This leads to discontinuities which may be mathematically insignificant, but psychophyscially very significant. Because the screen plays a significant role in the tone reproduction and a digital system supplies a finite number of points to be input to the system, its probably a good idea to examine the interactions.

The assumptions made in this analysis are the following:

1) The reciprocity law is valid over the region of interest
2) A linear change in digital value corresponds to a linear change in irradiance (and hence exposure)
3) The microstructure of the screen is known and understood.

Digital to analog converters rely upon linear mechanisms for their output. When dealing with such systems a numeric input will invariably lead to a linear change on output.

In a digital scanner system one could imagine that the reproduction characteristics could be described by Figure 4.

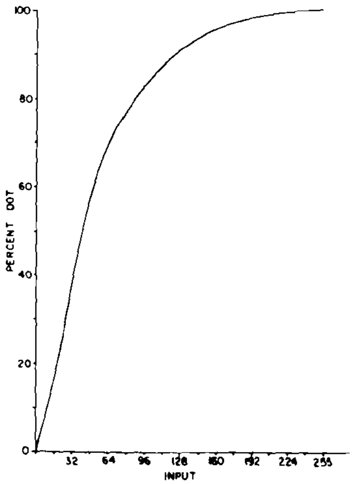

Figure 4: Digital scanner tone reproduction with negative screen

On the horizontal axis we plot N, the numeric value input to the digital to analog converter. On the vertical axis we plot percent dot. The data plotted in Figure 4 is from a screen used on a conventional scanner. Note that there is a very rapid change in percent dot with increase of numeric value. This leads to some severe problems which are illustrated in Figure 5. In Figure 5 we plot the log of numeric value versus percent dot. Note that for small numeric values a one count change is really quite large. Hence there are large gaps in the available percent dot percentages.

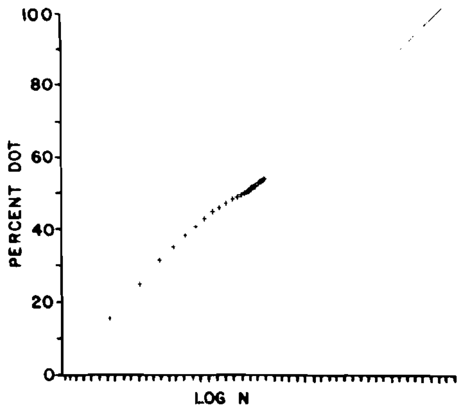

Figure 5: Percent dot versus log exposure

An examination of a two-dimensional density distributor of the screen (Figure 6) reveals why its performance is not good, for a wide dynamic range digital system.

The first problem is the density range of the screen. A typical digital system has an 8 bit range of values. If the digital section is driving a laser and intensity modulator, the range of possible exposures probably exceeds 500:1 (a log range of about 2:7). The worst feature of this particular screen is that in the regions of minimum density, there is almost no change. It is this characteristic which renders it most useless for digital applications. A very small change in illumination in the low density region of the

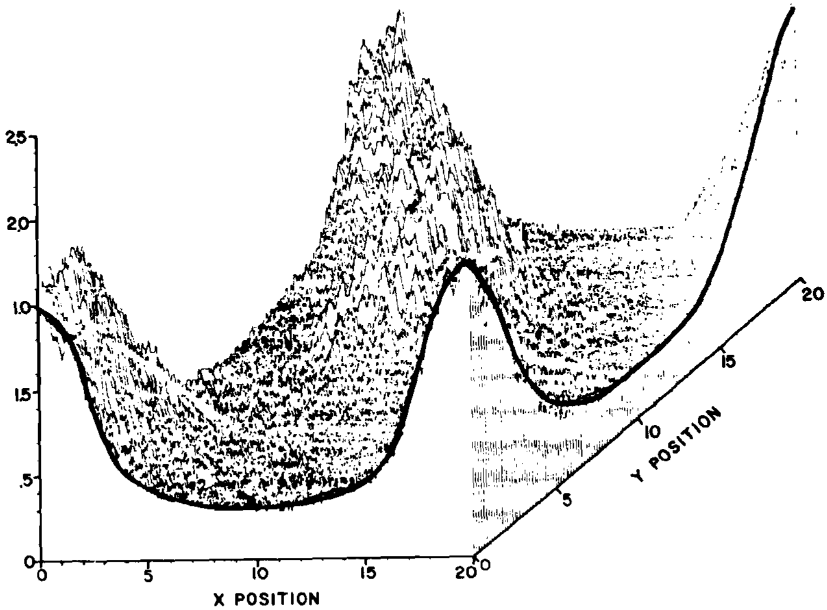

Figure 6: Two-dimensional density profile of screen

screen causes very rapid changes in dot growth. In the digital system, it is precisely this region where there are rapid changes in exposure due to quantizing. A digital change from 1 to 2 is a .3 log exposure change. The only hope is to underexpose. This positions the minimum percent dot in a region where smaller changes are made with each successive increment. Note also that there are fewer exposure levels available. This may lead to further complications.

The "Ideal" Screen Profile

The "ideal" screen profile in a digital system is not used for control of the tone reproduction, but for reliable and repeatable dot generation. As stated earlier, the assumption is that a linear change in numeric value will yield a linear change in exposure. To derive a linear percent dot change with change of exposure, the transmittance as a function of density must follow a square root-like function (see Figure 7). If one assumes a circular shaped dot, the dot area is proportional to

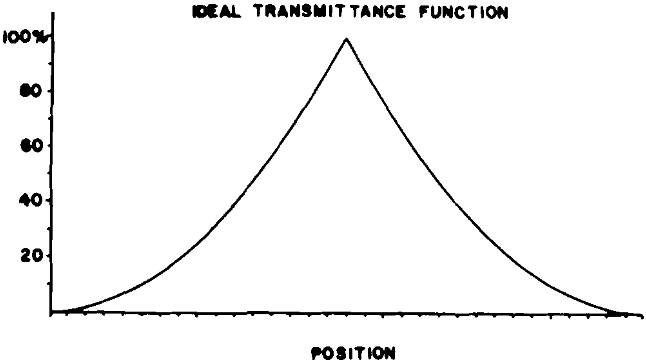

Figure 7: Square root transmittance function

the square of the radius. This relationship holds true until the dots just begin to touch (about 78% dot area). The illustration in Figure 8 demonstrates how this is calculated. For a square box of dimension "d" on a side, the total area, A_b, is given by d^2. The four circles which are just touching each have a radius of d/4 and their combined areas A_c are given by

$$A_c = 4 \times \frac{\pi d^2}{16}$$

The percent dot is equivalent to

$$\text{Percent dot} = \frac{A_c}{A_b} \times 100 = \frac{100\pi}{4} = \times\ 78.5 \text{ percent}$$

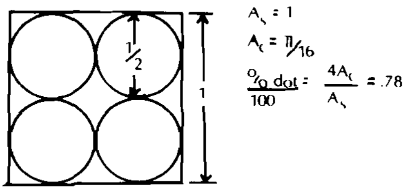

Figure 8: Calculation of percent dot for circular dots up to 78% dot

If one examines the density profile of ideal transmittance function, it appears as in Figure 9. One should note that this profile is very similar to that of a positive screen. In the case of the

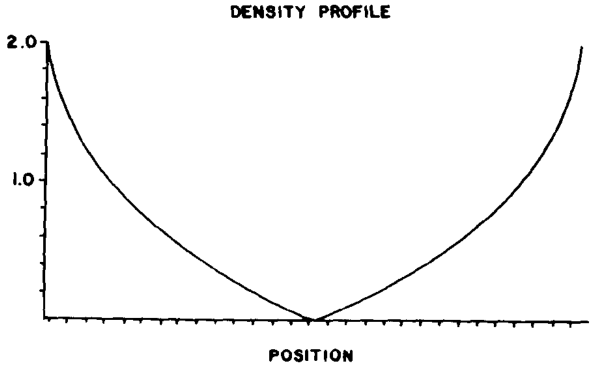

Figure 9: Density profile of "ideal" screen

digital scanner with the aforementioned assumptions, a positive screen is required regardless of the output. The reversal and tonal mappings are done in the scanner front end. A good starting screen would be a positive screen with a basic density range of 2.0 or more.

Use of a Laser for Single Dot Generation

Traditional electronic dot applications use many small dots to form a single large dot of known size. The digital methods are quite good, but they do require a good deal of very fast digital hardware. For applications that don't require the high resolution and are cost sensitive one can image that an amplitude modulated laser beam might be used to generate a dot on a lith material or plate.

For a laser operating in mode TEM_{00} the normal expression for the intensity profile is given by

$$I(r) = I_o e^{-\left|\frac{r^2}{\sigma^2}\right|}$$

where I_o is the peak intensity
r is the radius
σ is the $\frac{1}{C^2}$ points

A plot of this function is given in Figure 10 for a variety of levels of I_o. This corresponds to modulating the laser.

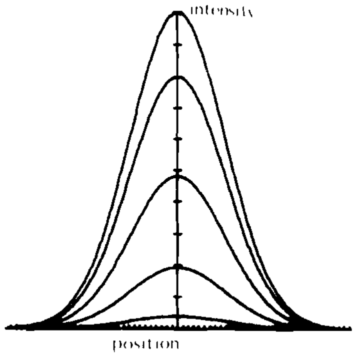

Figure 10: Modulated Gaussian beam

If one models the tone reproduction characteristics of this system combined with a digital modulating system, one finds that a similar problem exists with the system that appeared in the screen used in an earlier example. The Gaussian profile is not a good reproducer of dots. The parabolic profile in density is similar to that of a negative contact screen. Note, that in regions of lowest density the dot width is growing the quickest. This system was modeled mathematically and the reproduction of the system is given in Figures 11 and 12.

Adjustment of the Laser Intensity Profile

By exploiting the coherence properties of the laser and some useful properties of physical optics, an optical system can be designed which enables the beam profile to be modified to produce a better profile. The principles behind such systems are fully described in references 3 and 4.

The basic problem is to convert a Gaussian beam profile to some other function. The mechanism which we shall use is the optical Fourier transform. When illuminated with coherent light, the spot formed in the back focal plane of the lens is a scaled Fourier transform of the exit pupil

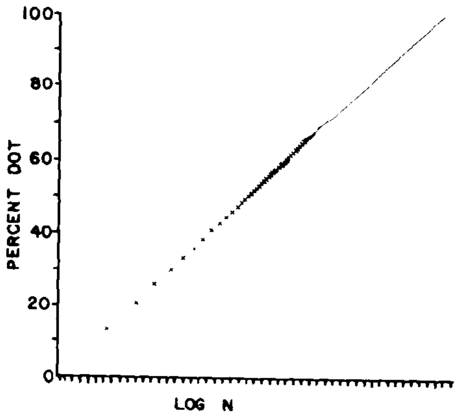

Figure 11: Log Gaussian percent dot mapping

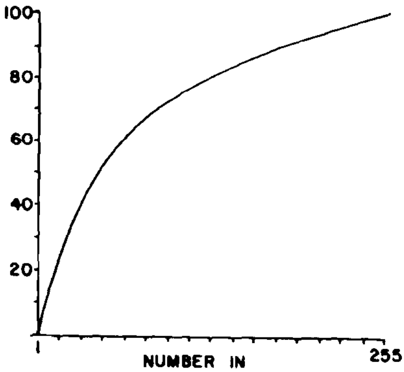

Figure 12: Gaussian output plotted against linear change in exposure

distribution. If one modifies the pupil image, the resultant spot is changed. Figure 13 is a schematic of the Fourier transform optical system used for these tests.

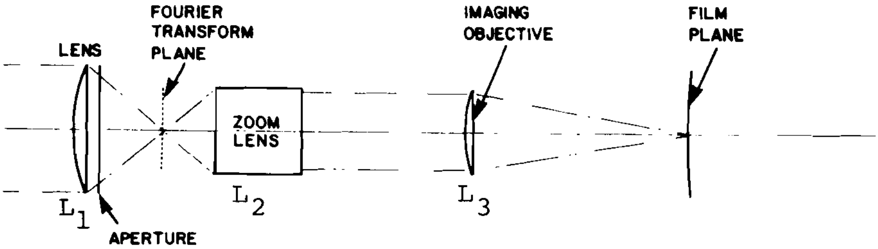

Figure 13: Fourier transform plane

The lens L_1 is the spot shaping objective. A mask is placed at or near its pupil and is an amplitude mask. The image formed is projected by the zoom lens. A zoom lens is used to make up for scale errors in the mask and lens L_1. L_3 focuses an image of the spot onto the film. An aperture mask is calculated by taking the inverse Fourier transform of the square root of the desired spot distribution. The assumption is made that the phase term is identically equal to zero and the square root of the modulus of the Fourier transform squared is equal to the transform itself. The result will be a transmission profile (Figure 14). This profile is converted to density (Figure 15) and an aperture mask is generated on film, using laser recording techniques, to satisfy this requirement.

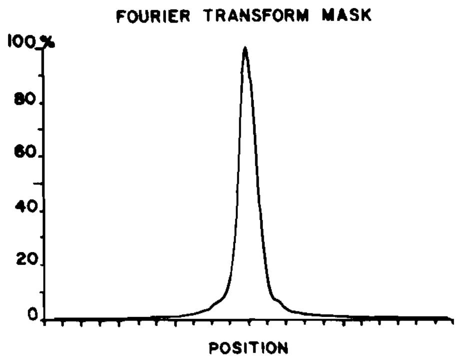

Figure 14: Fourier transform mask

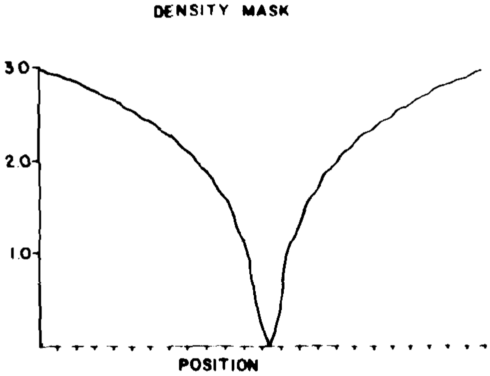

Figure 15: Density profile of required mask

Conclusions

For digital recording systems incorporating linear light attenuators, the most suitable screen for halftone recording is a wide range positive screen. Negative screens enhance digital artifacts and require a very non-linear correction to achieve suitable results.

References

1. Mess and James, The Theory of the Photographic Process, ch. 22.

2. Ewald Noemer, The Handbook of Modern Halftone Photography.

3. Hecht and Zajac, Optics, Addison-Wesley.

4. Optical Transforms. ed. H.S. Lipson, Academic Press.