第3卷 第2期
1983年3月

光 学 学 报
ACTA OPTICA SINICA

Vol. 3, No. 2
March, 1983

Realization of predictable contact screens

MOHAMMAD A. KARIM
(*School of Engineering Technology, University of Arkansas at Little Rock, U. S. A.*)

(Received 19 April 1982)

Abstract

The design process of contact screens have been investigated. An advanced knowledge of the threshold transmittance is essential for design of reliable screens. Following the theoretical guideline a logarithmic, an exponential and a fidelity contact screen have been designed and fabricated. Experimental results on screen performance are also presented.

Introduction

In the printing and graphic arts industries, the halftone technique[1] has long been used in the reproduction of continuous-tone photographs. Basically a screen is used to transform an original photograph into a high-contrast halftone negative or positive that contains arrays of opaque dots with sizes varying according to the optical density of the original. Printing plates can then be photo-reproduced from the halftone photograph.

Marquet and Tsujiuchi[2] first reported that the halftone contact screen technique has the flexibility to be used for nonlinear optical image processing. Since then the technique has proved to be useful in achieving different monotonic and nonmonotonic nonlinear characteristics in a coherent optical data processing system. Examples are equidensitometry[3], pseudo-color[4], logarithmic filtering[5,6], level-slicing[7], analog-to-digital conversion[8,9] and image subtraction[10]. The importance of the technique in its application to image processing is clear. However the fundamental difficulty of the process remains to be the realization of predictable contact screens. In this letter, we present the design algorithm and test the predictability of the fabricated contact screens.

Anlysis

Nonlinear optical image processing using contact screens consists of either one or both of the following steps. The first step involves a mapping of the input intensity, I_{in}, through a mapping function f such that $I_{out}=f(I_{in})$, where I_{out} is the output intensity. It is important to note that both the input and output intensities are functions of spatial coordinates. The mapping function f can be made either linear or nonlinear through the design and use of contact screens. The output is in the form of a pulse-width or pulse-area modulated nonlinear image of the original. In the second step, when the modulated binary output in a transparency form is placed at the input plane of a coherent optical image processing system[6], many orders of diffraction patterns appear at the Fourier plane. A spatial filter may then be used at the Fourier plane to select or to modify any one or several diffraction orders in the spectrum. Thus the overall nonlinear relationship between the input and output depends on the spatial filtering as well as the contact screen process used in the first step.

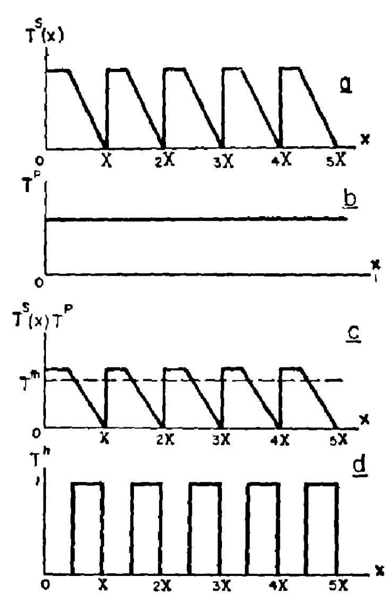

Fig. 1 Halftoning screening process: (*a*) Transmittance of few neighboring cells; (*b*) input transmittance; (*c*) combined transmittance of the screen in contact with the image; and (*d*) transmittance of the resultant halftone photograph

A contact screen normally consists of a periodic array of continuous-tone cell patterns on a glass or plastic substrate. Contact screens with random cell distributions are not considered in the present work. The contact screen can be used for transforming a continuous-tone photograph into a binary photograph through a contact printing process. In the process, the original continuous-tone photographic transparency or intensity distribution is contact-printed through the screen onto a high-contrast film. When the exposed high-contrast film is developed, the original gray tones are represented by the average transmittances of either area-modulated opaque dots if a two-dimensional screen is used or pulse-width modulated opaque bars if a one-dimensional screen is used.

The contact screen process using a specific one-dimensional screen can be illustrated with the help of Fig. 1. In Fig. 1 (*a*), the transmittance $T^s(x)$ of five unit-cells of the screen as a function of x is plotted. we assume that the continuous-tone original has a maximum spatial frequency less than the frequency of the screen so that the intensity transmittance T^p of the original over the region of at lest one unit-cell remains constant provided that edge effects are not considered. When the screen is in contact with the original image, the combined transmittance $T^s(x)T^p$ is shown in Fig. 1(*c*). When $T^s(x)T^p$ is equal to or greater than the threshold transmittance[11], T^{th}, the developed film will have a transmittance of nearly 0; otherwise approximately 1; as shown in Fig. 1(*d*). For convenience of discussion we may also define a threshold transmittance as

$$T^{th} = I^{th}/I_{in}, \tag{1}$$

where I^{th} and I_{in} denote the threshold energy and the energy of the input illumination respectively. The resulting photograph with binary levels of transmittance is called a halftone photograph, which is a spatially sampled version of the original.

For simplicity, our analysis will first be limited to screens of non-symmetrical one-dimensional (line) cell patterns only. As shown in Fig. 1(d), each group of equal-width halftone transmittance pulses corresponds to a constant input photographic transmittance, T^p. The screen transmittance is periodic with a period X, such that

$$T^s(x)=T^s(x+X) \tag{2}$$

The overall transmittance of a unit cell, T^H, may be defined as the ratio of the width of the transparent region to the total width of the unit cell. If the original is assumed to be sufficiently sampled, T^H can also be used to represent the regional average transmittance of the halftone photograph[11].

For $T^p \geqslant T^{th}/T^s$, the width of the transparent bar in the period of the unit-cell of the halftone photograph is $(X-x)$, where x is the value of x where

$$T^s(x)T^p=T^{th}. \tag{3}$$

When $T^p<T^{th}/T^s$ the film is not sufficiently exposed and the corresponding region of the halftone photograph will have a transmittance of nearly 1 (almost clear). For simplicity we assume that the transmittance is 1. Based on the above discussion, T^H may be written as,

$$T^H=\begin{cases}1-x/X, & T^sT^p\geqslant T^{th},\\ 1, & T^sT^p<T^{th}.\end{cases} \tag{4}$$

In addition, one may also write,

$$T^s(x)=\begin{cases}T^{th}/T^p, & T^p\geqslant T^{th},\\ 1, & T^p<T^{th}.\end{cases} \tag{5}$$

The functional dependence of T^H on T^p may be written as

$$T^H=f(T^p), \tag{6}$$

where for nonlinear mapping the form of the function f determines the nonlinear relationship.

Eqs. (4) and (6) can then be used to yield,

$$x=[1-f(T^p)]X, \quad T^p\geqslant T^{th}. \tag{7}$$

We shall now present three specific cases for the purposes of illustration: (a) the logarithmic case $f(T^p)=\alpha-\beta\ln(T^p)$, (b) the exponential case, $f(T^p)=\alpha\exp(\beta T^p)$, and (c) linear case, $f(T^p)=\alpha-\beta T^p$, where α and β are constants that makes $1\geqslant f(T^p)\geqslant 0$.

When function (a) is substituted into Eq. (7), we have

$$x=\left\{1-\alpha+\beta\ln\left[\frac{T^s(x)T^p}{T^s(x)}\right]\right\}X, \tag{8}$$

when function (b) is used, eq. (7) becomes

$$x=\left\{1-\alpha\exp\left[\beta\frac{T^s(x)T^p}{T^s(x)}\right]\right\}X, \tag{9}$$

and when function (c) is used, we would get

$$x=\left[1-\alpha+\beta\frac{T^s(x)T^p}{T^s(x)}\right]X. \tag{10}$$

Applying Eq. (3) to Eqs. (8), (9) and (10), we obtain,

$$T^s(x)=\begin{cases} T^{th}\{\exp[(\alpha-1+x/X)/\beta]\}^{-1}, & 1\geqslant\exp\left[\left(\alpha-1+\frac{x}{X}\right)\Big/\beta\right]\geqslant T^{th}, \\ 1, & \text{otherwise,} \end{cases} \tag{11}$$

for the logarithmic case,

$$T^s(x)=\begin{cases} \beta T^{th}\{\ln[(1-x/X)/\alpha]\}^{-1}, & 1\geqslant\frac{1}{\beta}\ln[(1-x/X)/\alpha]\geqslant T^{th}, \\ 1, \text{ otherwise,} \end{cases} \tag{12}$$

for the exponential case and,

$$T^s(x)=\begin{cases} \beta T^{th}\left[\alpha-1+\frac{x}{X}\right]^{-1}, & 1\geqslant\frac{1}{\beta}\left[\alpha-1+\frac{x}{X}\right]\geqslant T^{th}, \\ 1, \text{ otherwise,} \end{cases} \tag{13}$$

for the linear case. The limits in Eqs. (11)~(13) are set according to Eq. (5).

On the other hand, the average halftone transmittance, T^H, corresponding to screens of one-dimensional symmetrical unit cell patterns, is given by

$$T^s=\begin{cases} 2x/X, & T^p\geqslant T^{th}/T^s, \\ 1, & T^p<T^{th}/T^s. \end{cases} \tag{14}$$

Therefore, by substituting $2x/X$ for $(1-x/X)$ in Eq. (11), a logarithmic screen with a symmetrical cell transmittance can be designed to achieve

$$T^H=\frac{\ln(T^p)-\ln(T_{min})}{\ln(T_{max})-\ln(T_{min})}, \tag{15}$$

where T_{max} and T_{min} are the maximum and minimum values of T^p. In this case

$$T^s(x)=\begin{cases} T^{th}\left[\exp\left(\frac{2xk}{X}+\ln T_{min}\right)\right]^{-1}, & 1\geqslant\exp\left(\frac{2xk}{X}+\ln T_{min}\right)\geqslant T^{th}, \\ 1, & \text{otherwise,} \end{cases} \tag{16}$$

where $k=\ln(T_{max})-\ln(T_{min})$.

Similarly the one-dimensional symmetric exponential screen corresponding to

$$T^H=\exp[k(T^p-1)], \tag{17}$$

will have screen-cell transmittance

$$T^s(x)=\begin{cases} kT^{th}[k+\ln(2x/X)]^{-1}, & 1\geqslant[k+\ln(2x/X)]/k\geqslant T^{th}, \\ 1, \text{ otherwise,} \end{cases} \tag{18}$$

and one-dimensional symmetric high-fidelity screen corresponding to

$$T^H=T^p, \tag{19}$$

will have screen-cell transmittance

$$T^s(x)=\begin{cases}T^{th}[2x/X]^{-1}, & 1\geqslant 2x/X\geqslant T^{th},\\ 1, & \text{otherwise.}\end{cases} \quad (20)$$

It is essential to note that the accurate design of a contact screen requires a priori knowledge of T^s and T^{th} which is determined by the characterisitics of the high-gamma film selected, and the subsequent exposure and development of the film in making the halftone photograph.

Experiment

Symmetric one-dimensional logarithmic, exponential and linear contact screens are designed according to Eqs. (16), (18) and (20) with the values of T_{min}, T_{max} and T^{th} set at 0.01, 0.63096, and 0.02 respectively. The theoretically calculated transmittance of half of a cell of a symmetric logarithmic screen versus distance is shown by the solid line in Fig. 2 and the corresponding experimentally fabricated screen transmittance of a 23-step, 11-transmittance level screen cell is shown by the dashed line in the same figure. Likewise, the transmittance of half of a cell of the exponential screen and that of fidelity screen versus distance are shown respectively in Figs. 3 and 4.

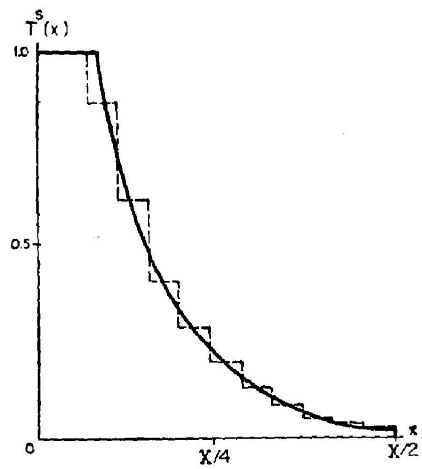

Fig. 2 Transmittance of half of a symmetric cell of a logarithmic screen versus distance. The theoretically calculated values are shown by the solid line and the experimental data by the dotted line

For the fabrication of the screens, a mask is used. The mask has a photographic periodic intensity transmittance function $T(x)$ of period X and

$$T(x)=\begin{cases}1, & 0<x\leqslant X/23,\\ 0, & X/23<x\leqslant X.\end{cases} \quad (21)$$

In making the contact screen, an Agfa-Gaevert 10E56 glass film plate is placed below and in close contact with the mask. A uniform incoherent light source is placed above the mask. After exposing the film and the mask by the light source for a predetermined time, the glass film is translated a distance of $X/23$ along the x-direction by means of a controllable translation stage while the mask is kept fixed. A second exposure is then made. The process of stepping a distance $X/23$ and exposing for a predetermined time period is repeated until the 22nd translation and the 23rd exposure are completd. The time period of exposure are determined by the transmittance of each step that is required in the unit cell of the screen.

For our purpose the mask was chosen to have a period of 0.0308 cm. The exact

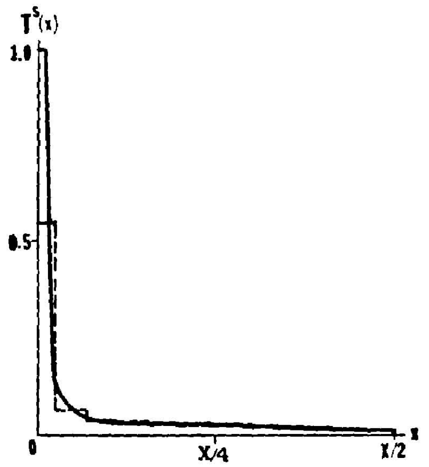

Fig. 3 Transmittance of half of a symmetric cell of an exponential screen versus distance. The theoretically calculated values are shown by the solid line and the experimental data by the dotted line

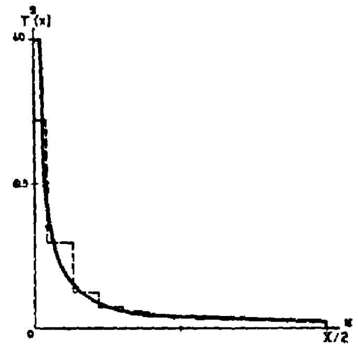

Fig. 4 Transmittance of half of a symmetric cell of a fidelity screen versus distance. The theoretically calculated values are shown by the solid line and the experimental data by the dotted line

transmittance values of Figs. 2, 3 and 4 were achieved by careful control of the exposures and the development conditions.

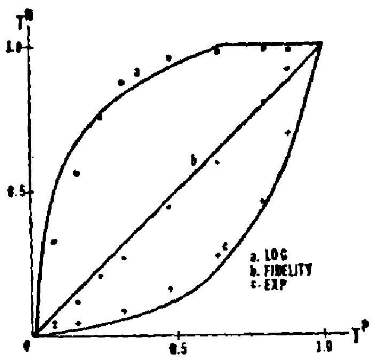

Fig. 5 The average transmittance of the processed gray scale versus the transmittance of gray scale input

For quantitative evaluation of the effectiveness of the fabricated contact screens, a particular gray scale was processed with each of the three contact screens. The density of the gray scales were measured by a densitometer. The transmittance of the processed gray scale were then plotted against the transmittance of the input gray scale with result shown in Fig. 5. It is shown that the experimental data corresponds significantly to the theoretical expectations.

The general theoretical format for the design of the screens should also be applicable to the design of other types of contact screens. The contact screens have been fabricated by approximating the theoretical screen profile by 23 steps.

参 考 文 献

[1] J. W. Wesner; *Appl. Opt.*, 1974, **13**, No. 7 (Jul), 1703.
[2] M. Marquet, J. Tsujiuchi; *Appl. Opt.*, 1961, **8**, No. 3 (Jul), 267.
[3] H. K. Liu, J. W. Goodman *et al.*; *Appl. Opt.*, 1976, No. 10 (Oct), 2394.
[4] H. K. Liu, J. W. Goodman; *Proc. SPIE*, 1976, **83**, 125.
[5] H. Kato, J. W. Goodman; *Appl. Opt.*, 1975, **14**, No. 8 (Aug), 1813.

[6] M. A. Karim, H. K. Liu; *Opt. Lett.*, 1981 **6**, No. 5 (May), 207.
[7] S. R. Dashiell, A. A. Sawchuk; *Appl. Opt.*, 1977, **16**, No. 4 (Apr), 1009.
[8] H. K. Liu; *Appl. Opt.*, 1978, **17**, No. 14 (15 Jul), 2181.
[9] H. K. Liu; *Opt.Lett.*, 1978, **3**, No. 6 (Dec), 244.
[10] D. Z. Zhao, C. K. Chiang *et al.*; *Opt. Lett.*, 1981, **6**, No. 11 (Nov), 490.
[11] M. A. Karim, H. K. Liu; *Opt. Lett.*, 1980, **5**, No. 3 (Mar), 132.
[12] H. K. Liu, M. A. Karim; *Opt.Lett.*, 1981, **6**, No. 7 (Jul), 319.

密着网屏的设计

MOHAMMAD A. KARIM
(*School of Engineering Technology, University of Arkansas at Little Rock, U. S. A.*)

提 要

本文研究了用于印刷和书画艺术复印工业中的密着网屏的设计方法。为了设计可靠而实用的网屏，最重要的是预先了解临界(阈值)透射率。作者以一维网屏为例，分析了密着网屏的网目透射率空间变化函数。根据这一理论分析，设计并制作了对数、指数和保真的密着网屏。文章最后给出了网屏性能的实验结果。

收稿日期：1982年4月19日

(上接第118页)

2. 非线性光学现象的一般问题

对两种简并的四波混频，认为如果其后向光有相位共轭性质，则应能复原工作物质中的畸变。利用四波混频作相位共轭镜，制成激光器，可以自激振荡($R>100\%$)，并可校正质量。

液体中的四波混频，认为可分为两类：一类是透明介质，一类是吸收介质。由于液体分子比较复杂，如何用 $\chi^{(3)}$ 描述吸收，没有完善的处理。

关于参量过程和非参量过程的相位匹配条件问题，认为从微观角度来讲，都要求能量守恒和动量守恒，所以受激也好、参量过程也好，都要求相位匹配。从物理概念来看，由于折射率不同而导致相速度不同，要满足动量守恒就必须使基频与倍频光的相速度相同，或者“同步”，或者相干叠加。

3. 相干光散射问题

代表们对虚能态的问题展开了两种截然不同观点的争论。一种认为存在虚能态，虚能态具有一定寿命，因为光与物质相互作用须要一定时间(那怕极短暂)。倘若存在中间实能态，就可把一个CARS过程看成是一个Stockes过程和一个反Stockes过程的叠加，它们不要求满足相位匹配，而CARS过程要求满足相位匹配条件，这样就不好理解。另一种观点认为不存在虚能态，因为如果有虚能态，则寿命极短，实现粒子数反转有困难，需要很大泵浦功率，与事实不符。四波混频为中间实态而不是虚能态。共振四波混频过程是一种直观的物理实在，有共振就有一定对应的实能态。

讨论中也有认为虚能态是微扰论的数学需要，是一种瞬时复合态，一现即逝。

(下转第145页)