ALGORITHM FOR THE DESIGN OF PRECOMPENSATED CONTACT SCREENS*

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ABSTRACT

The contact screen includes preprocessing step for converting the continuous level image into a pulse-width modulated binary image. The process is limited by the fact that no practical recording medium has hard-clipping characteristics. An algorithm for the precompensation design model is presented herein and is thereafter used to actually fabricate a precompensated nonlinear contact screen corresponding to low-gamma 4127 Kodak commercial film. The performance of the realized screen effectively demonstrates the usefulness of the algorithm.

THERE has been increasing interest in the advancement of methods for the optical implementation of nonlinear signal processing systems[1]. One of the more flexible techniques has been the use of contact screen process in coherent optical systems, through which analog-to-digital converstion[2], equidensitometry[3], homomorphic filtering[4], logarithmic filtering[5], pseudocoloring[6], and a variety of other nonlinear transformations[7] can be achieved. The process relies essentially on the contact screen characteristics. However, the fundamental difficulty of the technique remains to be the realization of dependable contact screens[8]. Due to the nonbinary response of the recording media significant gray area appears at the halftoned picture that causes irreversible problems in the processing of images. The purpose of this paper is to elaborate the precompensation design model[9] for the realistic fabrication of precompensated contact screens suitable for nonlinear optical image processing. We also report the performance of a specific nonlinear contact screen fabricated using this algorithm.

A contact screen normally consists of a periodic array of cell-patterns on a glass or plastic substrate. In the process, the input continuous-tone intensity distribution is contact-printed through the screen onto a hard-clipping recording media. When the exposed recording medium is processed, the original gray tones are represented by the average transmittances of either area-modulated dots if a two-dimensional screen is used or pulsewidth modulated opaque bars if a one-dimensional screen is used. This pre-processing step results in a mapping of the input photographic intensity transmittance, T^P, through a mapping function f such that $T^H = f(T^P)$. where T^H is the average intensity transmittance of the halftone photograph. The modulated halftone photograph is usually used at the input plane of a coherent optical image processing system[5]. Thus the overall nonlinear relationship between the optical system output and the continuous-tone input depends on the coherent system as well as on the halftone preprocessing step.

The majority of existing screen design algorithms are based on the assumption that a hard-clipping recording medium is used for making the halftone input. But this restricted assumption is an oversimplification of the actual response of the recording medium. An uncompensated screen, therefore, when used would produce gray areas in addition to the usual binary black and white.

For the sake of simplicity, we shall limit the algorithm to nonsymmetrical line screen of cell period X, such that $T^s(0) > T^s(x)$, where $T^s(x)$ denotes screen-cell transmittance at x. We assume further that the continuous-tone original has a maximum spatial frequency of the screen so that the transmittance T^P of the original over the region of at least one unit-cell remains constant. The energy incident on the recording medium at position x is, therefore, given by

$$E(x) = eT^PT^s(x), \tag{1}$$

where e is the incoming light intensity incident on the input original. The transmittance of the resulting halftone photograph, T^h, is typically related to the incident energy E as follows:

$$T^h(E) = \begin{cases} 1 & \text{if } 0 \leqslant E \leqslant E_1 \\ 0 & \text{if } E_2 \leqslant E \leqslant \infty. \end{cases} \tag{2}$$

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*Part of this paper was presented in the 27th Midwest Symposium for Circuits and Systems in Morgantown, West Virginia.

The general nature of the $T^h(E) \sim E$ curve is shown in figure 1.

The algorithm for the design of precompensated nonlinear monotonic contact screen can be summarized by the following steps:

Step I. Determine the function $f(T^P) = a - b[g(T^P)]$ where a and b are two constants and $g(T^P)$ specifies the exact nature of the screen mapping. Examples of two such mappings are (i) power mapping: $g(T^P) = (T^P)^n$, where n is a constant and (ii) logarithmic mapping: $g(T^P) = \ln(T^P)$. The values of a and b for every specific mapping are predetermined such that $0 \leqslant [T^H = f(T^P)] \leqslant 1$ for all allowable values of T^P.

Step II. Determine the equivalent threshold transmittance, $T^{\mathrm{th}}_{\mathrm{eq}}$, for the recording medium such that

$$T(E) = \begin{cases} (E/E^{\mathrm{th}})^{-\gamma} & \text{for } E^{\mathrm{th}} \leqslant E \\ 1 & \text{for } E < E^{\mathrm{th}}, \end{cases} \tag{3}$$

where $E^{\mathrm{th}} = eT^{\mathrm{th}}_{\mathrm{eq}}$ and γ is the slope of the linear portion of the corresponding Hurter-Driffield curve[10].

Step III. Solve for $g(T^{\mathrm{th}}_{\mathrm{eq}})$ using the integral[9,11]

$$T = \left[X - \int_{T^s(x_2)}^{T^s(x_1)} eT^P T^{h'}(E)\, t(\tau)\, \mathrm{d}\tau\right] \Big/ X \tag{4}$$

where

$$eT^P T^s(x_1) = E_1; \quad eT^P T^s(x_2) = E_2$$

$$\tau = T^s(x); \quad T^{h'}(E) = \mathrm{d}T^h(E)/\mathrm{d}\tau$$

$$t(\tau) = [1 - f(T^{\mathrm{th}}_{\mathrm{eq}}/T^s(x))]X \text{ when } T^P \geqslant T^{\mathrm{th}}_{\mathrm{eq}}$$

and $t(\tau)$ is the function inverse to τ. As for example, for the general power mapping $g(T^{\mathrm{th}}_{\mathrm{eq}})$ is obtained as

$$g(T^{\mathrm{th}}_{\mathrm{eq}}) = (T^{\mathrm{th}}_{\mathrm{eq}})^n = \left[e^n \int_{E_1}^{E_2} \{T'(E)/E^n\}\, \mathrm{d}E\right]^{-1} \tag{5}$$

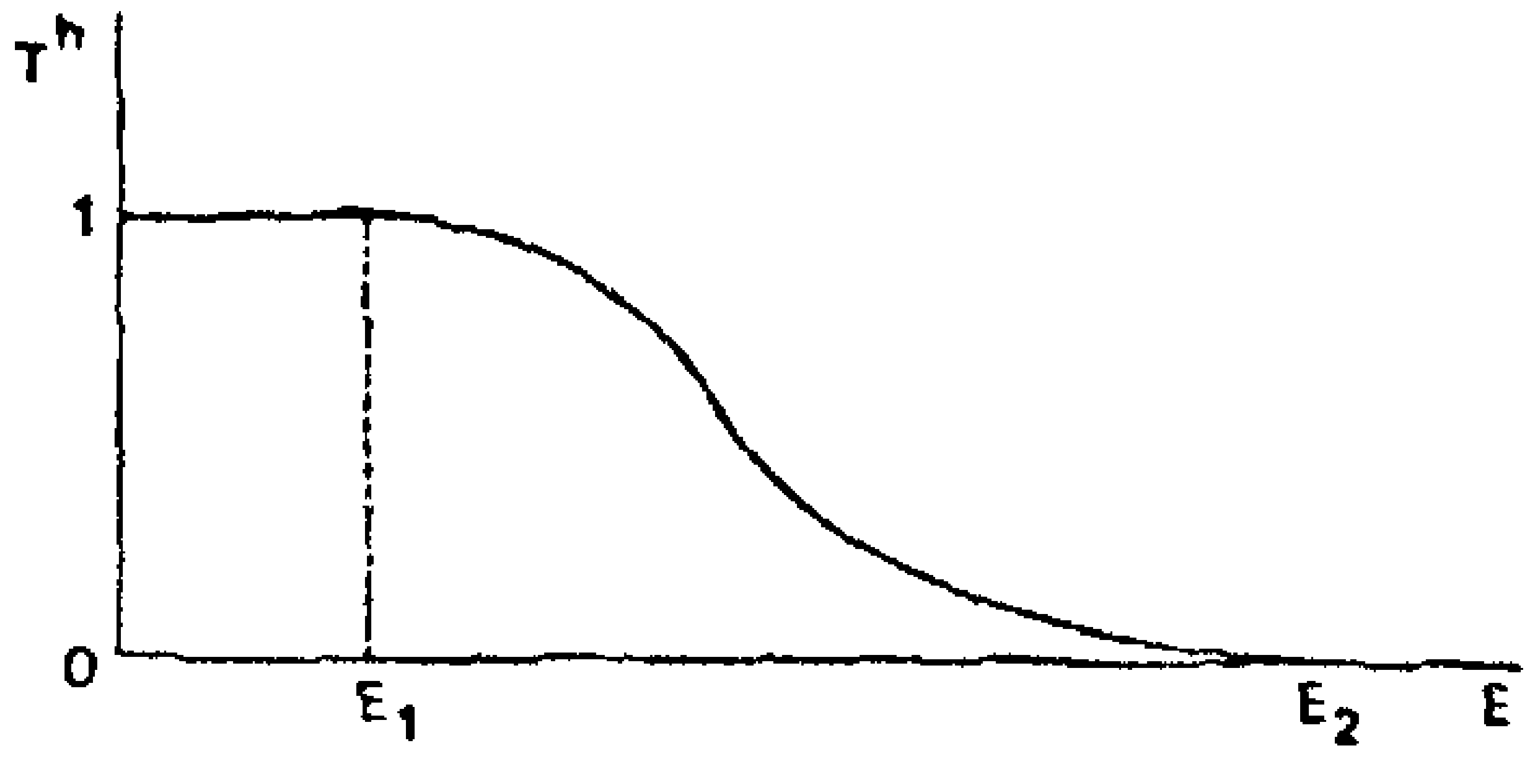

Figure 1. The halftone transmittance versus exposing energy—the general characteristics.

Step IV. Solve the equation[9,11]

$$g\left(\frac{T^{\mathrm{th}}_{\mathrm{eq}}}{T^s(x)}\right) = \left(a - 1 + \frac{x}{X}\right) \Big/ b \tag{6}$$

for $T^s(x)$ using (3), and $g(T^{\mathrm{th}}_{\mathrm{eq}})$ from Step III.

Step V. Realize screen transmittance by means of the Ronchi-ruling translation-exposure method[3].

To experimentally verify the design model an attempt is made to generate a precompensated nonlinear screen of mapping $T^H = 1.00 - 0.88(T^P)^2$ corresponding to 4127 Kodak commercial film. Use of this mapping function results in the screen transmittance given by

$$T^s(x) = T^{\mathrm{th}}_{\mathrm{eq}}\left[0.88 \Big/ \left\{\frac{\gamma}{\gamma+2}(x/X)\right\}\right]^{\frac{1}{2}}. \tag{7}$$

The solid line of figure 2 shows the theoretical screen profile while the dashed line represents the transmittance of the experimentally realized 23-level secreen[12]. For the actual fabrication of the screen, a mask of period 0.0308 cm is predesigned to have the periodic intensity transmittance, $T^m(x)$, given by

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

In making the screen, an Agfa-Gaevert 10E56 glass

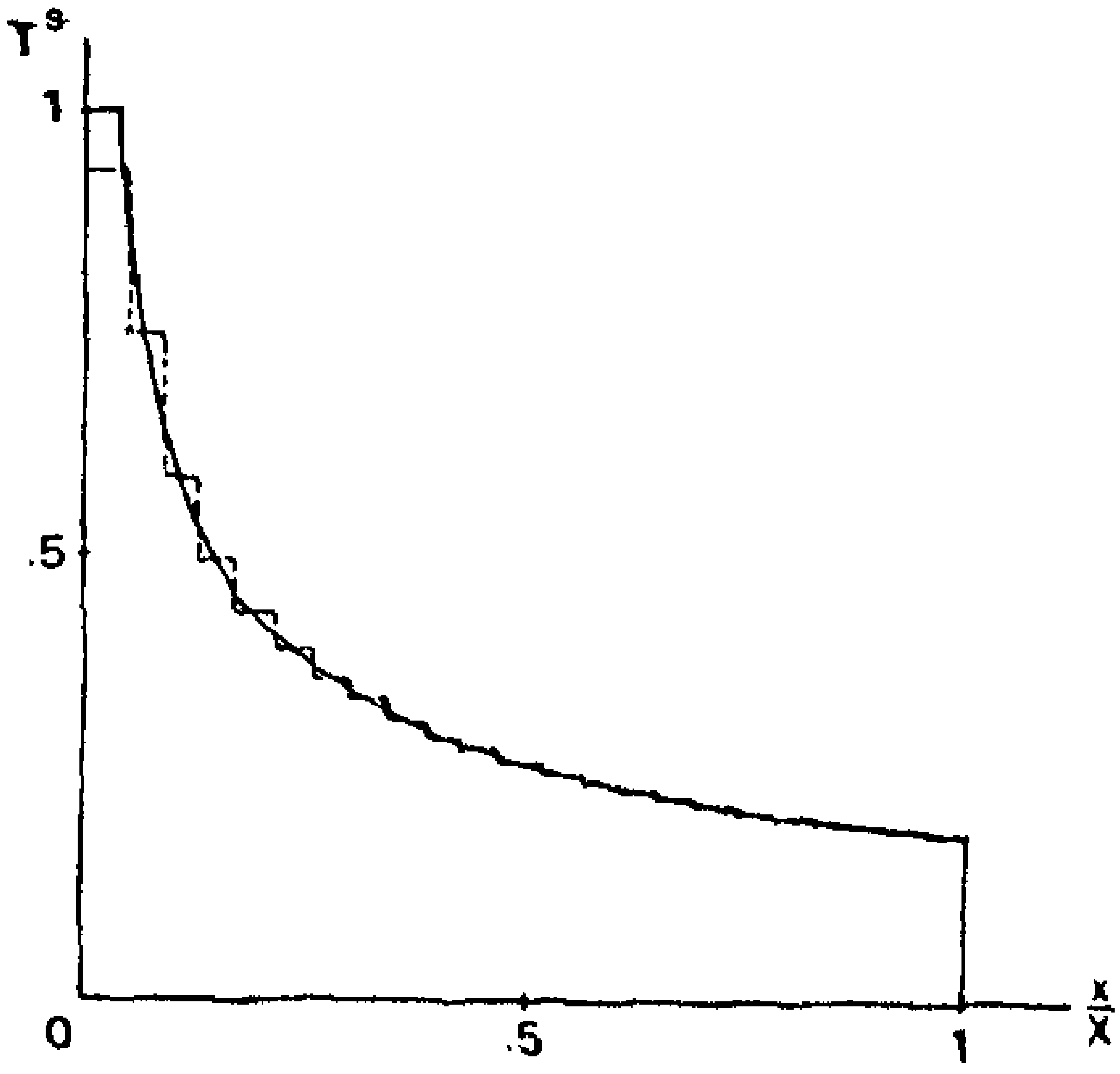

Figure 2. Screen profile of half of a nonsymmetric screen cell versus distance corresponding to $T^H = 1.00 - 0.88(T^P)^2$. The theoretically calculated values are shown by the continuous line and the experimentally realized profile by the dashed line.

film plate is placed below and in close contact with the mask. An incoherent 300W light source is placed about 3.05 *m* above the mask to guarantee uniform distribution of light. After exposing the plate and the mask to the light-source for a predetermined time, the glass film is translated a distance of 0.01339 mm along the x-direction by means of a translation stage while the mask is kept fixed. A second exposure is then made. The process of translating a distance of 0.01339 mm and exposing for a predetermined time is repeated until the 22nd translation and the 23rd exposure are completed. The durations of the exposures are determined by the transmittance of each step that is required to suit the 23 level screen criterion of figure 2. A particular gray scale was then processed with the contact screen so designed. The transmittance of the processed gray scale was plotted against the transmittance of the input gray scale and is shown in figure 3. It is seen that the experimental data correlate significantly with theoretical predictions.

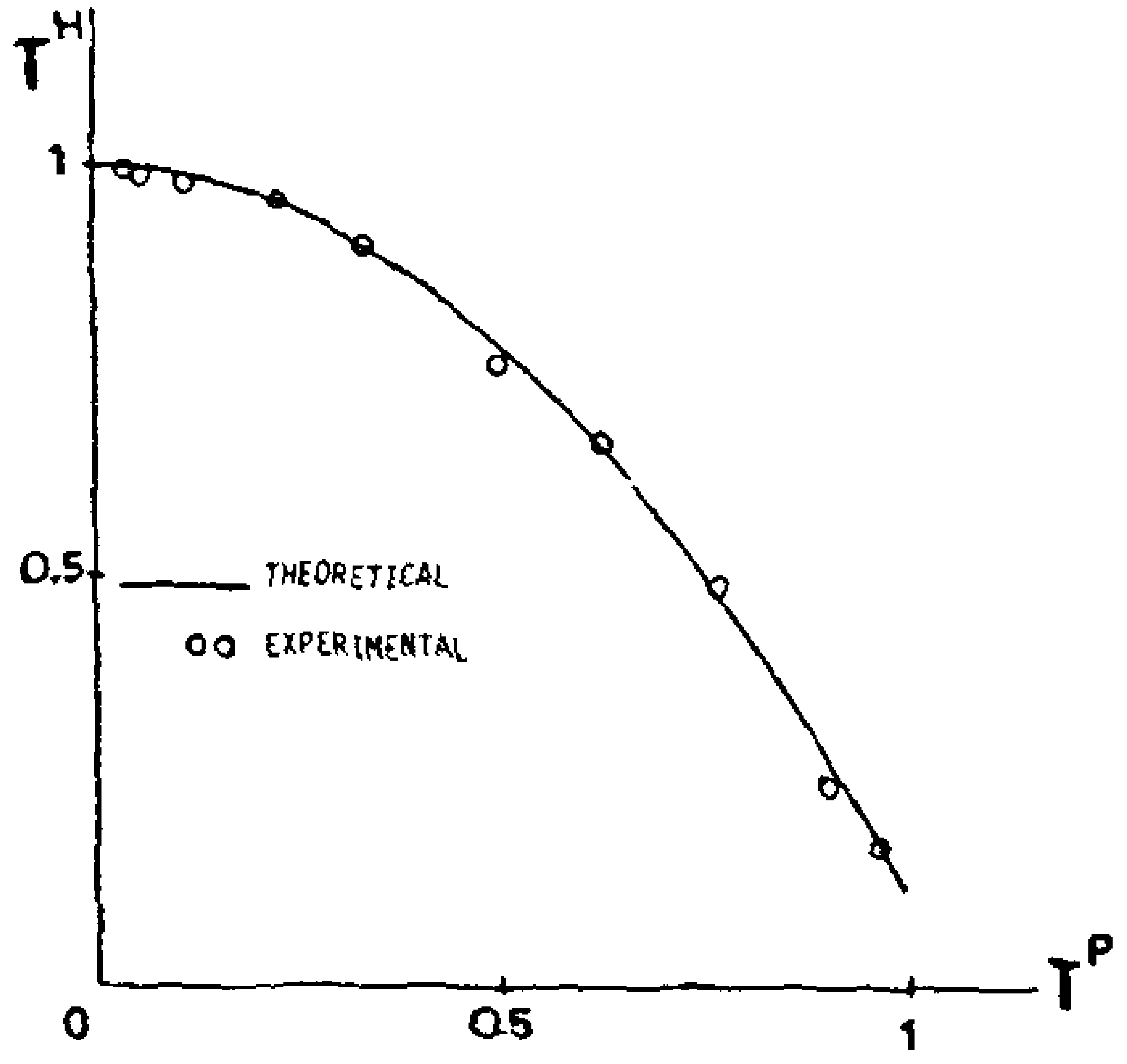

Figure 3. *The average halftone transmittance of the processed gray scale versus the transmittance of the gray scale input.*

The algorithm is very general and can be readily used for realizing any monotonic nonlinear optical processing using any realistic recording media—photographic or real-time. Unlike the density-based algorithm of Dashiell and Sawchuk this transmittance-based algorithm has actually been used to realize precompensated screen using a very inexpensive set-up. The translation-exposure technique is much faster than that using the computer-controlled microdensitometer. Currently work is in progress towards realizing a high-performing optical homomorphic image processing system using precompensated contact screens.

29 December 1984

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