A method of calibrating a photo optical system for determining spatial relationships

E. Glab
D. Zimmerman

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A METHOD OF CALIBRATING
A PHOTO OPTICAL
SYSTEM FOR
DETERMINING SPATIAL RELATIONSHIPS

Senior Research Project
In partial fulfillment of the requirements
for the Bachelor of Science Degree
Rochester Institute of Technology
Rochester, New York

by
E. Glab
D. Zimmerman

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ABSTRACT

A technique is described for the calibration of a photo-optical system. This technique yields a response surface. Measurements of image density and image width taken from a microdensitometer trace can be related through this response surface to object dimensions.
INTRODUCTION

With the increasing use of the photographic image in recording data in compressed form, a quantitative analysis of the image is assuming greater importance.

Spatial dimensions are among the many measurements that can be made on an image. The dimensions of a photographic record are related to the size of the objects and the system magnification. These, however, are not the only factors which are effective in determining the size of the image.

The spatial dimensions of a photographic record can be affected by many factors. These factors include: 1) Optical spread function, 2) Dimensional stability of the film base, 3) Emulsion turbidity, 4) Gelatin creep, 5) Processing edge-effects, 6) Irregularities in drying and handling, 7) Object width, and 8) Exposure.

Many of the factors mentioned above are very difficult to determine and the sum total of their effect on a system is even more difficult to predict. It is our intention to develop a method for calibrating a photo-optical system to yield object widths if image width and image density are known. Image width and image density are the most directly measured parameters and usually the easiest to analyze from a micro-densitometer trace. A complete system as defined by the authors consists of an imaging device, photosensitive material, processing technique, and an instrument for determining density and image width.
The usual procedure for checking spatial distortion is to image, by contact or through an optical system, a pattern onto the photographic emulsion. The film is processed and the resulting measurements are made over spaces, lines, or widths, at different exposure levels or density increments on the negative image or master.

Targets which can be used for this purpose are:

1. Line-spectra comparisons of an element in a spectrograph, (distance between lines is independently known).\(^1\)
2. Reseau grid of positional points (squares). Deviations have experimentally fitted a second-order equation.\(^2\)
3. Moire patterns of glass-mounted master halftone tints superimposed on a diapositive.\(^3\)
4. High-contrast transmission target in Lambertian source field.

The widening of the image with increasing exposure has been used by astronomers for many years instead of methods depending on density measurements.\(^4\) None of the proposed formulas have been found to be universally acceptable because the exposure criterion is not easily transferred to different situations.

\(^1\)H. Gallnow and G. Hagemann, "Displacement of Photographic Emulsions and a Method of Processing to Minimize This Effect," Astronomical Journal, Vol. 61, Number 9, November, 1956, p. 399


Mees, in 1909, imaged various sizes of slits through an intensity modulated wedge which varied the exposure logarithmically from the top to the bottom of the slits. The resulting image showed definite spreading of the slits in a tadpole-like configuration.

Correlation of image distortions with density levels seems to be more applicable than correlation with exposure criteria because density response is more easily measured in different situations than exposure criteria are. The record of exposure in the film is density, so it seems appropriate to correlate density with image distortion.

There are four basic instruments available for measuring the spatial distribution of the image. They are: 1) Double-screw comparator, 2) Filar eyepiece micrometer, 3) Projected images on graph paper, and 4) Recording microdensitometer. The errors and drawbacks inherent in the first two instruments are associated with eyestrain, operator fatigue, eye adaptation, and retinal illumination and rotational inaccuracies. The disadvantage of the method used by Stevens with the superimposed graph paper is judging where the edges are to be located on the screen.


The disadvantage of using a microdensitometer for measuring spatial
distance on the image is that the instrument is difficult and time-
consuming to operate.

The basic advantage of the microdensitometer over the other
instruments cited is that the results obtained are more objective,
thus, avoiding some of the bias and variability inherent in human
observers.

A technique is developed which relates the input variables of
density and object width with the output variable of image width. These
relationships can be used to calibrate a photo-optical system under
restricted conditions to yield object width when image width and image
density are measured under the stated conditions.
OBJECTIVES

To find a functional relationship between object width, image density, and change in image width.

Definitions

Object Width (O.W.) is determined by using the optical section of the Ansco microdensitometer as an optical comparator. The edge of the target is visually aligned with the ground glass reticle and the vernier reading recorded. The target is moved manually until the opposite edge is aligned with the same reticle. Difference of vernier readings is the object width.

Image Width (I.W.) is determined by a microdensitometer trace at a density of 0.30 above base-plus-fog.

The output (dependent variable), Deviation in Image Width, is the deviation in image width from proportional change in O.W. and at densities different from O.W. reference density. Expressed mathematically, the output, \( (D.I.W.) = I.W. - M(O.W.) \), where M is the magnification factor.

The M will be defined at a reference level of 0.50 density and at a 4000 micron object width. Thus, at these predetermined reference levels, magnification is the ratio of the image width to the object width under the conditions of the above explained reference O.W. and density level.
If magnification were the only thing operating upon the spatial dimensions, the response surface would be a flat plane parallel to the density axis and positively sloped in the direction of object width. The slope would be equal to the magnification of the system. No real photographic system operates in this ideal manner.

Deviation from the ideal response function described above includes all the factors which have an effect on image spatial dimensions including experimental error. D.I.W. is a measurement of the magnitude of these factors.

**Hypothesis**

\[ H_0: \text{D.I.W.} = B_0 + B_1X_1 + B_2X_2 + B_{11}X_1^2 + B_{22}X_2^2 + B_{12}X_1X_2 + E \]

\[ H_1: \text{D.I.W.} = \text{Function lower than quadratic} \]
EXPERIMENTAL PROCEDURE

A target was constructed by attaching strips of black tape of widths 1/4 inch, 1/2 inch, 3/4 inch, 1 inch, and 1 1/4 inches onto a white reflecting card 16 inches square in parallel rows spaced 2 inches apart. This pattern was photographed on lithographic film at approximately 1/8 magnification to yield a high contrast negative transmission target.

The system chosen to test the calibration technique consisted of the following components:

1. Microimage camera with vacuum platen for holding the film in place
2. Kodak High Definition Aerial Film, Type 3404 (Estar Thin Base)
3. Processing and handling of the exposed films
4. Microdensitometry on the images at certain selected parameters of slit width, sample speed, magnification, and chart speed

The target was imaged through a Wratten #58 green filter placed between the light source and the target. The film was placed on the vacuum platen of the camera and the image densities were varied by changing the shutter speeds between 1/10 to 1/200 second for a series of exposures. Each exposure series was repeated at various increments of focus settings. Twenty increments of focus settings were used to insure best focus within the limits of the increments used.

\[^9\text{Chart-Pak Tape, black matte, tolerance on the width is } \pm .002 \text{ inch}\]
The film was processed in standard formula D-19 for five minutes at 68°F. This was followed by thirty seconds in SB-1, eight minutes in F-6, wash for twenty minutes, and a rinse in 0.5% Photoflow—all at 68°F. The film was dried at room temperature for a minimum of twenty hours. Brush agitation was applied to the film which was taped face up in 8" x 10" trays during the wet stage of processing.

The best-focused density set was selected by microdensitometer tracing of images from different focus increments. These traces were compared and the exposure set yielding the greatest edge-gradient was assumed to represent the best of that focus series. The best-focused exposure series was completely traced at all bar widths and at all density levels to yield experimental data. The experimental data was obtained by measuring the width of the above traces at a density amplitude of 0.30 above base-plus-fog. For an illustration of this method of obtaining data, see Figure 1.

Width measurements taken from the microdensitometer chart are converted to microns by using appropriate conversion constants to account for chart speed and sample-stage speed. For sample calculation, see Appendix. The procedure was repeated to obtain four complete replicates. At this point, the data represents image widths at various density levels for five different object widths.

Discrete levels of density were impractical to obtain experimentally, therefore, a line of best fit was applied to each set of replicated points. This gave four line replicates of density vs. image width. These line replicates were then used to find the response surface of
I.W. vs. density and O.W. At a density of 0.50 and O.W. of 4000 microns, the magnification of the system was calculated. Data was then converted to D.I.W. and the response surface of D.I.W. vs. density and O.W. was calculated using the Forward Doolittle technique.

The purpose of converting data from I.W. to D.I.W. was to demonstrate the failure of the system to magnify at a constant ratio for different object widths and different density levels.
RESULTS

From the data, a response surface or functional relationship was derived which relates deviation of image width with image density and object width. The response surface is illustrated in Figure 2.

The null hypothesis was rejected on the basis of an analysis of variance for multiple curvilinear regression. The alternate hypothesis, a multiple linear regression, was tested and found to be significant. Therefore, the alternate hypothesis was accepted.

Determination of the D.I.W. response surface makes it possible to determine object width if image width and image density can be measured.

For this system operating under the stated conditions, the equation for the response surface is given by:

\[ D.I.W. = -0.989 + 0.000861(O.W.) + 10.136(Density) + 0.000696(Density)(O.W.) \]

and is defined as:

\[ D.I.W. = I.W. - M(O.W.) \]

Substituting equation one into equation two and solving for O.W. yields:

\[ O.W. = \frac{(I.W.) + 0.989 - 10.136(Density)}{M + 0.000861 + 0.000696(Density)} \]

Confidence limits on the response surface are given in Table 1. Graphical representation of confidence limits for an object width of 3200 microns is shown in Figure 3.
CONCLUSIONS

A technique was developed for quantitatively relating object dimensions with image width and image density. This calibration correlates object width with measurements made from a microdensitometer trace of density amplitude and image width.
SAMPLE CALCULATION SHOWING THE CONVERSION
FROM WIDTH OF THE MICRODENSITOMETER TRACE (INCHES)
TO WIDTH OF THE IMAGE (MICRONS)

Image Width (microns) = Trace Width (inches) $\times \frac{\text{stage speed}(\text{mm/min})}{\text{chart speed}(\text{inches/min})} \times \frac{10^3 \text{ microns}}{\text{mm}}$

or

Image Width (microns) = Trace Width (inches) $\times 31.25 \text{ microns/inch}$
**TABLE 1**

**CONFIDENCE LIMITS COMPARISONS FOR D.I.W. RESPONSE SURFACE**

<table>
<thead>
<tr>
<th>Object Width (microns)</th>
<th>Spread of Confidence Limits (microns) Density 0.4</th>
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<td>3989.35</td>
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<td>±0.60</td>
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TABLE 2

DATA POINTS FOR OBJECT WIDTH = 3176.50 MICRONS
(with computation for confidence limits)

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\[ s_{xy} = \frac{42.57}{18} = 2.36 = 1.54 \]

95% Confidence Level

limit \pm Y at 0.4 density = \pm (1.54)(2.14) \sqrt{\frac{1}{18} + \frac{(0.4 - 1.2)^2}{3.52}} = \pm 1.68

limit \pm Y at 1.2 density = \pm (1.54)(2.14) \sqrt{\frac{1}{18} + \frac{(1.2 - 1.2)^2}{3.52}} = \pm 0.82

limit \pm Y at 2.0 density = \pm (1.54)(2.14) \sqrt{\frac{1}{18} + \frac{(2.0 - 1.2)^2}{3.52}} = \pm 1.68
BIBLIOGRAPHY


