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Accurate Photogrammetry and Photographic Nonlinearities

Significant errors are introduced in making photogrammetric measurements without correcting for nonlinearities.

Introduction

One method for performing photogrammetric tasks is to measure the distance between two visual alignments with a comparator. The visual location of image boundaries is made difficult by photographic blur and granularity. These factors introduce random errors which can be eliminated by averaging a series of measurements. However, photographic nonlinearities can distort boundary density profiles and produce systematic errors. These errors cannot be eliminated by multiple measurements. Two significant photographic nonlinearities are the sensitometric properties of the original and duplicating films and the near-field diffraction associated with contact printing.

Abstract: *A computer simulation showed that significant errors could be introduced by photographic nonlinearities in otherwise accurate photogrammetric procedures. A technique was developed to determine automatically dimensions from photographic images. This procedure functions in the presence of linear and nonlinear degradations and photographic granularity, and has produced accurate measurements for laboratory and operational cases.*

The nonlinearity of the duplicating film and the contact printing process can be eliminated by making measurements on the original film; however, the sensitometric nonlinearity of the original negative film remains. A study was conducted to determine the magnitude of the errors introduced by photographic nonlinearities in an otherwise accurate photogrammetric procedure. As these errors were found to be significant, a technique was developed which accurately determines the dimensions of objects from photographic images in the presence of linear and nonlinear degradations and photographic granularity.

Photographic Nonlinearities

A study was conducted to determine the magnitude of the errors introduced by neglecting the effect of photographic nonlinearities in the performance of mensuration tasks. In order to reduce costs, a computer simulation was performed rather than an actual experiment. The schematic arrangement of the computer simulation is given as Figure 1. The procedure consisted of the following steps:

- The reflectance profile of the desired ground object was generated.
- The profile was convolved with the line-spread function of the camera/film combination to simulate the degradation of the camera exposure process.
- The resulting profile was taken from exposure to transmittance values by a sensitometric conversion corresponding to the original negative film.
- The measurements were performed by obtaining the distance between the middle transmittance values of the image edge boundaries.
- The transmittance profile was convolved with the spread function of the printer/film combination to simulate the image degradation during duplication.

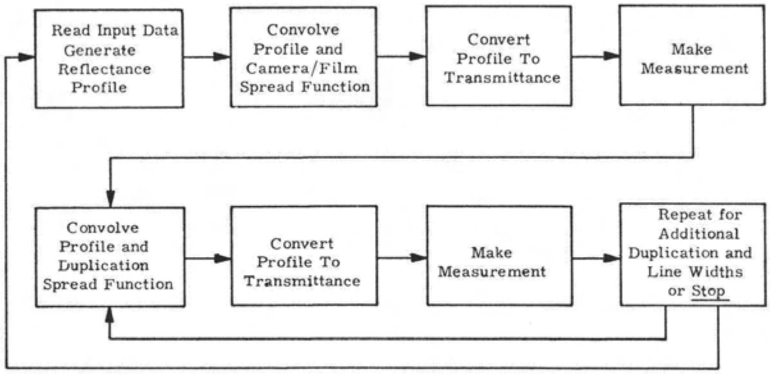

FIG. 1. Schematic diagram of the computer simulation for photograph nonlinearities.

- The resulting profile was taken through a sensitometric conversion corresponding to the duplication process.
- The measurement process was repeated.
- Steps 5 through 7 were repeated as many times as desired.

The test involved determination of the width of line-type objects. Typical spread functions and sensitometric curves were used for the camera and original film — Kodak 3404. A previous investigation had indicated that duplication with the Eastman Kodak—Niagara Printer and Kodak 2430 film produced edge images with diffraction effects.[1,2] The resultant spread functions of the printing process were determined experimentally and shown in Figure 2.

The simulations of four different width lines through four duplication generations are shown in Figure 3. It should be noted that the simulation process does not add grain noise to the imagery which could obscure the *fringes* seen on the simulated profiles. Table 1 lists the width measurements determined from the simulated line profiles. It can be seen from the table that significant errors exist for most instances, with larger errors for the positive images than the negative images for the particular degradations used.

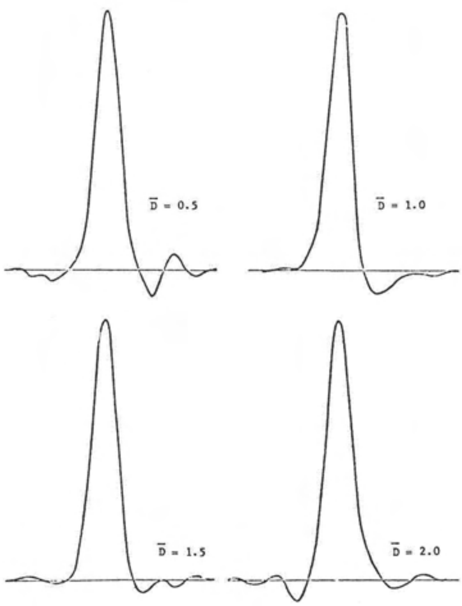

FIG. 2. Spread functions of the duplication process using the Eastman Kodak Niagara Printer at 120 feet per minute. $\bar{D}$ stands for mean density. (Spread functions taken from Reference 1.)

AUTOMATIC MENSURATION

A method was developed which determines the dimensions of photographic images of various target objects. The preliminary effort dealt with obtaining the width of target objects which were recorded as line images. The technique's purpose is to provide accurate image measurements in the presence of camera system degradation (image blurring), photographic granularity, and film and duplication process nonlinearities.

The first step in the procedure is to determine the camera/film system optical transfer function. A suitable edge image, which corresponds to a brightness step edge in the scene, is located. This edge image should be located as parallel and near the line image as possible. The edge image is scanned perpendicular to the edge to produce one dimensional digitized data. (If possible, this scan should be made on the original film recording as this eliminates the need to remove the effects of the duplication processes.) A high-speed computer and the edge-gradient computer program[3,4] are used to develop the camera system/film optical transfer function from the edge scan data.

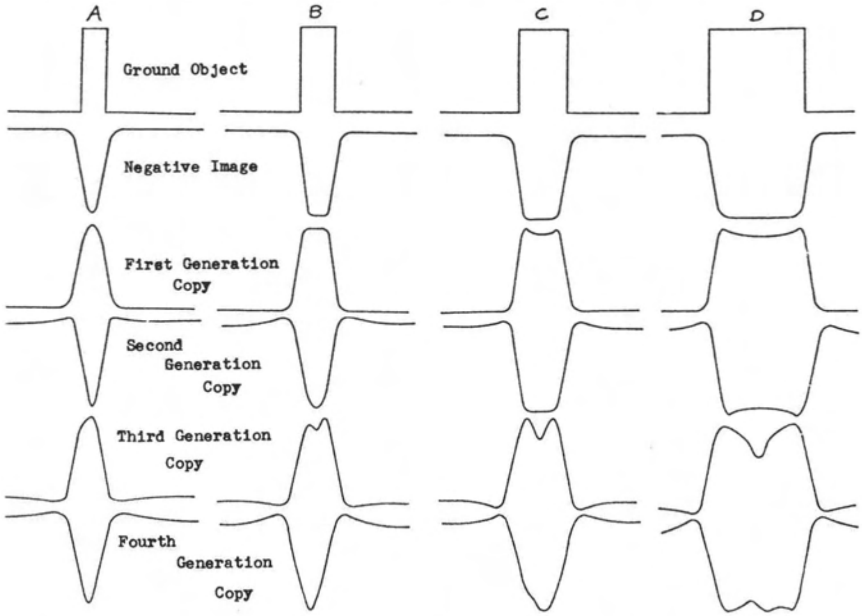

FIG. 3. The computer simulation of line-transmittance profiles through four duplication generations. The instances correspond to line-image widths of A, 10 μm; B, 14 μm; C, 20 μm; and D, 40 μm.

Next, the line image is scanned perpendicular to the edges to provide one dimensional digitized data. The image scan data are taken through a sensitometric conversion to exposure domain. The Fourier transfer of this exposure data is obtained, producing the one-dimensional frequency spectrum of the image. This function is then divided by the system modulation transfer function to produce the enhanced frequency spectrum. It should be noted that if the images correspond to a copy, each film sensitometric relationship and duplication degradation must be removed (going from last to first) prior to removal of taking camera/film effects.

If this enhanced frequency spectrum is transferred back to distance space, a sharp line image would not be produced. The spatial frequency data have been truncated at a frequency (kc) which produces an effective image degradation, because all frequencies are required to reconstruct an edge image. This fact has been illustrated by taking the enhanced frequency spectrum of a line image and transforming back to distance space. The results shown in Figure 4 show that the resultant data does not resemble a perfect line image.

The problems of incomplete frequency information and high-frequency photographic noise can be eliminated by making the measurement directly from the enhanced frequency spectrum data. Because the object is that of a rectangular pulse, the frequency spectrum will be of the form $(\sin \pi a k) / \pi a k$ or $\mathrm{sinc}\ \pi a k$ for $k<k_c$ and indeterminate for k

TABLE 1. LINE-WIDTH MEASUREMENTS FROM SIMULATED LINE PROFILES

Image	*Line Width*			
True Dimension	10.0	14.0	20.0	40.0
First Generation Copy	11.2	15.4	21.6	41.8
Second Generation Copy	9.6	13.2	19.6	39.8
Third Generation Copy	12.4	16.0	22.4	43.4
Fourth Generation Copy	9.6	12.8	18.4	39.8

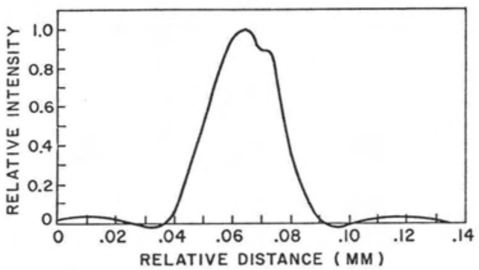

FIG. 4. Enhanced line image for test shown in Figures 7-9.

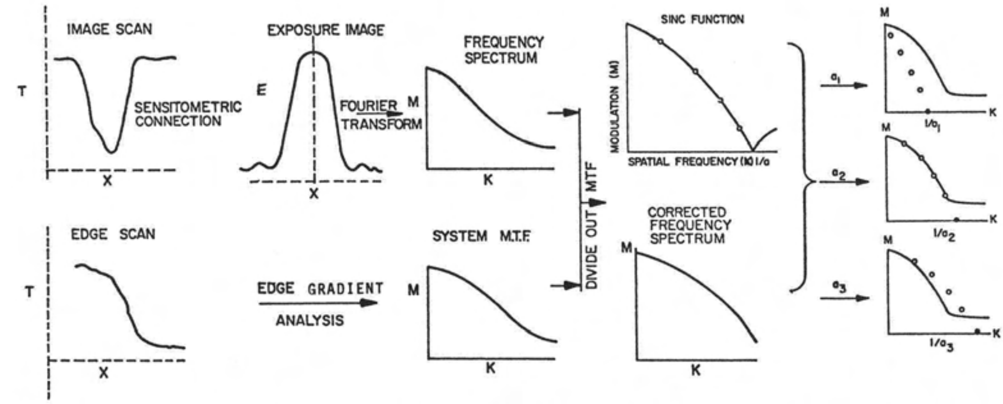

FIG. 5. Schematic drawing of the measurement technique. (Procedure operates on digitized data, but illustration shows analog data for clarity.)

$\geqslant k_c$, where k is the spatial frequency, a is the true width of the line image, and k_c is the frequency cut-off value.[5] The *sinc* function prior to the first zero crossing $(k < k_c; k < 1/a)$ is correlated with the operational data as a is varied. The value of a for the best correlation is taken to be the width of the line image.

Figure 5 is a schematic drawing of the measurement technique. The accuracy of the procedure depends on properly determining the system modulation transfer function and the lack of extraneous objects extremely near the target object.

A computer program has been written for the XDS 930 computer to perform automatically the measurement operation. A simplified flow diagram of the computer program is given as Figure 6. The computer requires the line-scan data, the system modulation transfer function, and film sensitometric function as inputs. The computer prints out the enhanced frequency spectrum, the line-width determination, and the associated correlation value.

TEST RESULTS

In order to test the techniques, an analytic trace of a square pulse degraded by a system modulation transfer function was used as input data. The computer determined the line width within 0.3 percent of the correct value.

The procedure was tested using a laboratory setup. A target array consisted of a low-contrast Air Force Bar Target, a photographic knife edge, and a linear density wedge were photographed on Kodak 3404 film using a Miranda 35-mm camera. The system was rigidly mounted on an optical bench, the lens stopped down to $f/16$, and the target array

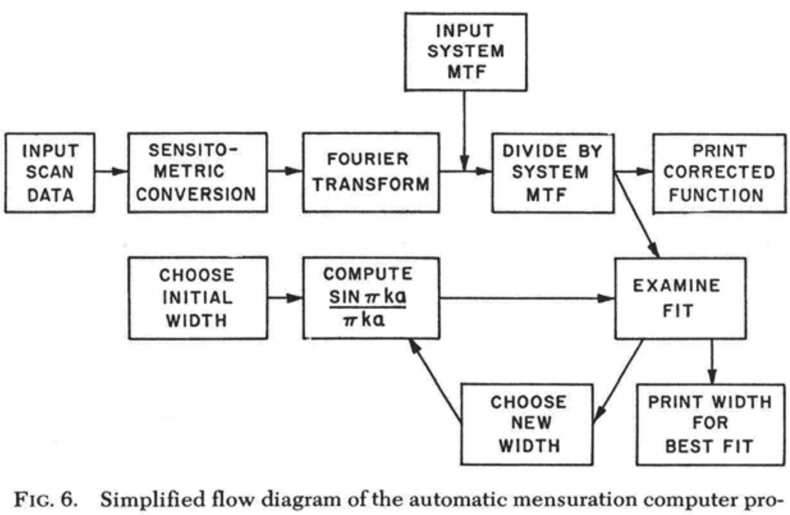

FIG. 6. Simplified flow diagram of the automatic mensuration computer program.

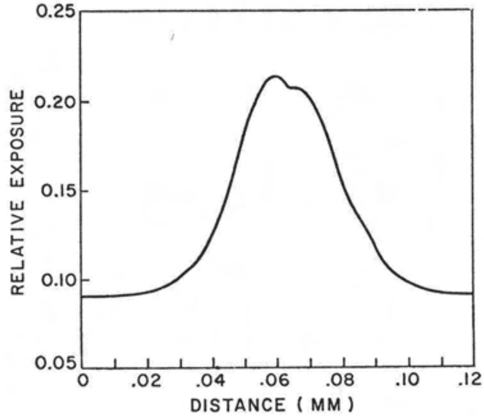

FIG. 7. Scan data for the test.

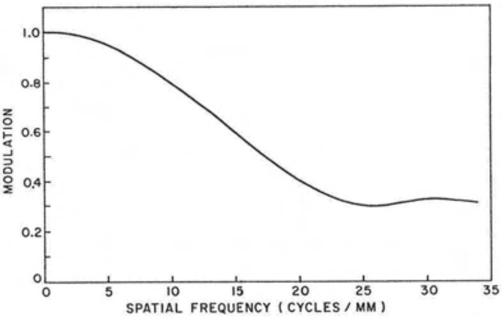

FIG. 8. System modulation transfer function for the test.

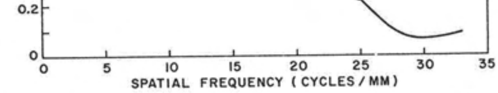

FIG. 9. Comparison of the *sinc* function and the enhanced frequency spectrum for the test.

photographed in varying degrees of defocus. A frame was selected where the bar image was noticably blurred. The images of the bar, edge and density wedge were scanned using the Perkin-Elmer Microdensitometer[6]; Figure 7 shows a bar-image scan. The system modulation transfer function was determined as given in Figure 8. The measurement tech-

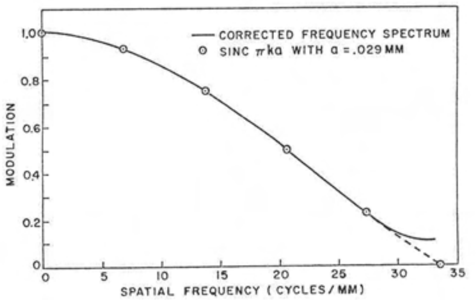

FIG. 10. Comparison of the *sinc* function and the enhanced frequency spectrum for a typical operation.

nique was applied to this data to produce a line width determination of 0.032 mm. This value was found to fall within 4 percent of the value determined from the known bar-target width and the photographic reduction factor. (The reduction factor was determined by careful measurement of a large distance in the image.) Figure 9 is a comparison of the *sinc* function and enhanced frequency spectrum for this case; good agreement can be seen.

The technique has been used on operational material with good results. For these applications, the true target dimensions were unknown. However, the good matches between the enhanced frequency spectrums and the *sinc* functions producing the best correlations indicate probable accurate measurements. Figure 10 is a plot of the fit of the sinc function to the enhanced frequency spectrum for one typical case.

CONCLUSIONS

Significant errors are introduced by photographic nonlinearities in making photogrammetric measurements using visual techniques. An automatic mensuration technique has been developed which has produced good results for both laboratory and operational applications.

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