# Consequences of Enlarging Small-Format Imagery with a Color Copier

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ABSTRACT: A commercial color laser-scanned copier enlarged 35-mm diapostives and prints from a Pentax 645 camera to a 30- by 42-cm format. Although 15 to 20 percent of the original imagery area was cropped, image deformation was relatively small. A dense array of targets on the original diapositives were measured and compared with corresponding measurements on the enlargements. Least-squares affine coordinate transformations showed RMS errors of 12 to 16 and 21 to 55 μm for the 35-mm and 645 format, respectively. For the 35-mm enlargements, skewness and stretch were approximately 1 mm. For 645 enlargements, stretch was 0.2 mm and skewness averaged 1.7 mm. Enlargement costs were 12 percent of conventional photographic techniques.

## INTRODUCTION

PROVIDED CAREFUL ATTENTION IS GIVEN to the rudiments of photogrammetry, 35- and 70-mm photography is capable of producing reliable measurements. Capturing accurate measurements, however, generally requires working with the original negatives or diapositives, because commercial enlargement changes some basic photogrammetric properties of the original image. Enlarging the film by conventional printing operations not only changes scale, but it also eliminates (crops) a portion of the image.

Needham and Smith (1984) detail two factors that account for this reduction in image area. First, the film aperture in an enlarger is smaller than the size of exposed film. This permits high speed production printing to proceed without requiring each negative to be precisely centered in the film holder. The second reason for cropping is a technique known as spillover: it eliminates edge problems on the prints by projecting the image beyond the edges of the paper. For 35-mm enlargements, these photographic procedures reduce image content 10 to 22 percent, depending on print size (Table 1).

The photogrammetric implications of enlargement are critical. First, determining the principal point may be difficult, if not impossible, because the film is rarely centered in the film holder. Second, distortion caused by the enlarger's lens system introduces systematic errors. And third, enlarging may change the tip and tilt orientation imparted to the original image if the planes of the film and the photographic paper (onto which the enlarged image is projected) are not parallel.

With the emergence of color copiers that digitally scan an image (rather than rely solely on optical projection), using enlargements of small-format images for photogrammetric purposes is being reconsidered. The purpose of this study was to explore the errors introduced by enlarging 35-mm and 645 format diapositives (transparencies) utilizing a Canon Colorlaser Copier (CLC-200).

## METHODOLOGY

The imagery was low-oblique aerial photography of a relatively flat, grass field (186 by 249 m) covered with 48 targets, taken with two non-metric cameras: a 35-mm Pentax LX and a Pentax 645 fitted with a variety of lenses. The 645 (which uses 120/220 or 70-mm film) differs from the 70-mm formats in that the frame size is rectangular (approximately 6 by 4.5 cm). Film type was Ektachrome ASA 200, processed commercially.

After viewing the exposed imagery, we selected frames that best approached the desired configuration (i.e., a dense array of targets covering móst of the image): five 35-mm and six 645 diapostives.The diapositives were placed on a Zeiss Planicomp analytical plotter, which has a point location accuracy of 1 to 2 μm, and an experienced operator measured all observable targets. These stored data, X and Y stage-coordinates, were considered true values.

The diapositives were then enlarged to an A-3 format (30 by 42 cm) utilizing a Canon Colorlaser Copier (CLC 200). Manufacturer specifications state the CLC 200 has a resolution of 400 dpi (dots [pixels] per inch), and a gradation of 256 tones per color (blue, green, red). The copier could enlarge directly from 35-mm slides or from prints. Enlarging the 35-mm diapostives necessitated mounting them in glass slide frames. At the time of this investigation the copier was not equipped to handle the dimensions of a 645 slide; therefore, the diapositives were commercially enlarged to 10- by 15-cm prints, then enlarged to an A-3 format.

Each enlargement was placed on a Wild Aviotab TA2 plotting table, configured for digitizing purposes, and all observable targets were measured and stored. The TA2 has a 20-μm resolution with motors driving in 10-μm increments. Although not

TABLE 1. IMAGE LOSS CAUSED BY ENLARGING 35-mm NEGATIVE TO STANDARD PRINT SIZES (INFORMATION SUPPLIED BY EASTMAN KODAK COMPANY [NEEDHAM AND SMITH, 1984]).

| Print size<br>(inches)<br>(cm) | 3.5 × 5<br>9 × 13 | 4 × 6<br>10 × 15 | 5 × 7<br>13 × 18 | 8 × 10<br>20 × 25.5 | 8 × 12<br>20 × 30.5 |
|---|---|---|---|---|---|
| Enlargement factor | 3.84 | 4.40 | 5.44 | 8.64 | 8.80 |
| Effective film format (mm) | 23.151 × 33.073 | 23.106 × 34.636 | 23.379 × 32.684 | 23.520 × 29.399 | 23.092 × 34.636 |
| Image area lost in printing (%) | 13.82 | 9.92 | 13.99 | 22.17 | 9.97 |

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TABLE 2. IMAGE LOSS CAUSED BY ENLARGING DIAPOSITIVE USING THE CANON COLOR LASER 200.

| Format[1] (mm) | enlargement factor | enlarged format area ($cm^2$) theoretical[2] | actual | image area lost in enlarging (%) |
|---|---|---|---|---|
| 35 mm | | | | |
| 36.367 × 24.202 | | | | |
| image 1 | 12.7 | 1419.6 | 1108.4 | 21.9 |
| image 2 | 12.6 | 1397.3 | 1100.3 | 21.3 |
| image 3 | 12.6 | 1397.3 | 1100.3 | 21.3 |
| image 4 | 12.7 | 1419.6 | 1104.3 | 22.2 |
| image 5 | 12.6 | 1397.3 | 1108.8 | 20.6 |
| mean | | 1406.2 | 1104.4 | 21.5 |
| stdev | | 12.2 | 4.2 | 0.6 |
| 645 | | | | |
| 56.015 × 40.934 | | | | |
| image 1 | 7.3 | 1222.2 | 1016.6 | 16.9 |
| image 2 | 7.3 | 1222.2 | 1010.1 | 17.2 |
| image 3 | 7.3 | 1222.2 | 1010.1 | 17.2 |
| image 4 | 7.2 | 1187.7 | 1003.6 | 15.5 |
| image 5 | 7.2 | 1187.7 | 1012.7 | 14.7 |
| image 6 | 7.2 | 1187.7 | 997.2 | 16.1 |
| mean | | 1205.0 | 1008.4 | 16.3 |
| stdev | | 18.9 | 6.9 | 1.0 |

[1]Measured by Zeiss Planicomp
[2](Measured format length × enlargement factor) (measured format width × enlargement factor)

calibrated, the TA2 exhibited good precision when tested. Specifically, 25 known points were measured off a 23- by 23-cm glass grid-plate, and then an affine transformation was computed. For three separate grid plates, the accuracy was approximately 20 μm.

The (TA2) enlargement measurements were compared with the true (Planicomp) diapositive measurements through a least-squares affine coordinate transformation. The transformation determined scale change (power enlargement), stretch, and skewness.

## RESULTS

### IMAGE LOSS (TABLE 2)

The amount (area) of image lost in enlarging was considerable – approximately 22 percent for the 35-mm and 16 percent for the 645 format. Table 2 illustrates image reduction based upon the difference between the theoretical and actual enlargement area. Image loss for the 35 mm might be attributed to cropping caused by the slide frame, whereas the 645's image loss might be primarly the effect of enlarging the diapositives to 10- by 15-cm prints. (Eastman Kodak Company states that enlarging a 35-mm negative to a 9- by 13-cm print reduces the original image area by approximately 14 percent [Needham and Smith, 1984].) In either case, image reduction may also be the result of spillover, the reason being this: the enlargements had 0.7- to 2.2-cm frame borders (with the 645 borders being nearly twice as wide as those on the 35-mm enlargements). Average dimensions of the 35-mm enlargements were 27.2 by 40.6 cm, whereas the 645 enlargments were 25.9 by 38.9 cm.

### IMAGE DEFORMATION (TABLE 3)

For the 35-mm imagery, the RMS residuals after the least-squares, affine fit were 14 μm at the scale of the original. The mean amount of stretch along the X axis was 1.02 mm (standard deviation, 40 μm), and mean skewness was 0.89 mm (standard deviation, 99 μm), at the scale of the enlargement.

For the 645 imagery, the RMS residuals after affine transformation were 41 μm. These high residuals are primarily attributed to the distortion introduced by enlarging the diapositives into prints: i.e., when image rays pass through the lens system of an enlarger, additional distortion is imparted to their location. To confirm this suspicion, the prints were placed on the Zeiss Planicomp analytical plotter and all observable targets were measured. RMS residuals after affine transformation were 34 μm at the scale of the original .

In addition, the targets on the 645 enlargements appeared fuzzier than on the 35-mm enlargements because the diapositives were enlarged twice (first by printing then with the cop-

TABLE 3. DEFORMATION OF ENLARGED IMAGERY.

| Format | Enlargement (p) | RMS residuals at scale of the original (μm) | X-Stretch at scale of the enlargement $([B_x - B_y] \times d)p$ (mm) | Skewness $(\Delta\delta \times d) \times p$ (mm) |
|---|---|---|---|---|
| 35 mm | | | | |
| d = 36.367 | | | | |
| image 1 | 12.7 | 12 | 0.978 | 1.036 |
| image 2 | 12.6 | 12 | 0.981 | 0.762 |
| image 3 | 12.6 | 16 | 1.058 | 0.906 |
| image 4 | 12.7 | 16 | 1.054 | 0.866 |
| image 5 | 12.6 | 16 | 1.046 | 0.867 |
| mean | | 14 | 1.023 | 0.887 |
| stdev | 0.05 | | 0.040 | 0.099 |
| 645 | | | | |
| d = 56.015 | | | | |
| image 1 | 7.3 | 53 | 0.375 | −1.787 |
| image 2 | 7.3 | 43 | 0.124 | −0.286 |
| image 3 | 7.3 | 45 | 0.321 | −3.450 |
| image 4 | 7.2 | 21 | 0.005 | −0.818 |
| image 5 | 7.2 | 44 | 0.314 | −2.290 |
| image 6 | 7.2 | 38 | 0.204 | −1.347 |
| mean | | 41 | 0.224 | −1.663 |
| stdev | 0.05 | | 0.140 | 1.124 |

d = frame length (mm)
p = enlargement power
$B_x - B_y$ = differential scale change of enlargement
$\Delta\delta$ = angle rotation of principal point

ier). Although stretch was smaller (0.224 mm), skewness was considerably greater than on the 35-mm enlargements, with a mean value of −1.66 mm (standard deviation, 1.1 mm).

## CONCLUSIONS

By working with original scale imagery, one avoids systematic errors introduced by commercial enlarging (e.g., cropping and distortion imparted by the enlarger's lens system). However, the relatively small scale requires an expensive measuring instrument like an analytical plotter, if one wants to exploit the inherent accuracy of the image. By enlarging the original imagery, one may be able to make the measurements with a less expensive and less accurate instrument like a digitizer, without losing overall accuracy.

Two consequences of enlarging small-format imagery are image loss and image deformation. With the exception of skewness in the 645 imagery – which might be attributed to the photographic procedures in making the 10- by 15-cm prints – the laser-scanned enlargement did not introduce significant image deformation. Nevertheless, it cropped a substantial portion of the image, 15 to 22 percent, which would effect basic photogrammetric considerations. Because small cameras are not fitted with fiducials, inner orientation is often based upon redundant frame-edge measurements (Warner and Carson, 1991). With the frame-edge cropped, a reliable inner orientation would require imagery from a camera fitted with a calibrated reseau plate. Despite cropping, enlarging small-format diapositives with a laser-scanned copier offers advantages, not the least of which is cost. For this study a 30- by 42-cm color enlargement cost 12 percent of the expenses associated with conventional photographic enlargement.

## REFERENCES

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## Erratum

In the December 1991 issue of *PE&RS* (Vol. 57, No. 12), the front cover images were switched. The legend correctly states that the shallower illuminated Cycle I image is left, the steeper-looking Cycle II image is right.