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Film Distortion in Non-Metric Cameras

One can expect an *RMS* value of 5 to 7 micrometers using a single scale factor to be reduced to 3 by using two factors with commercial 70-mm film.

Introduction

In reviewing the literature concerning film deformation, one finds that almost all of the experiments deal with films and film sizes used in metric aerial cameras. Accordingly, it is necessary to study the deformation of the films used in non-metric cameras developed under commercial laboratory conditions. The investigation reported in this article is directed only to the film deformations outside the camera. The film deformations caused by film flatness or any mechanism inside the camera are beyond the scope of this article. Two commonly used films in non-metric cameras were chosen for this study. These two films are black-and-white Kodak Tri-X Pan 70-mm (ASA 400) and black-and-white Kodak Plus-X Pan 70-mm (ASA 125).

The procedure used in this experimental study is similar to the glass-grid plate method, in which a negative of the reseau intersections appearing on a negative taken in a Hasselblad MK 70 camera is used as a grid. The grid has 25 points. The points are 10 mm apart.

Ten contact exposures were made from the grid onto each of the above two films. During the contact exposure the emulsion surface of the film was in contact with the surface of the grid. After developing all of the negatives, the reseau points appearing on the 20 negatives of the Kodak Tri-X Pan and Kodak Plus-X Pan, as well as the grid point, were measured on STK-1 Stereocomparator.

Abstract: *The accuracy of the object-space points obtained from non-metric cameras is controlled by the residual errors due to film deformation inside and outside the camera. The film deformation inside the camera is one of the properties of the camera. Two cameras of the same brand will have different film deformation. This article gives an estimation of the residual error due to film deformation outside the camera, in analogue and analytical approach, of two commercial films used in non-metric cameras.*

In this experiment the two films were treated like any film used in non-metric cameras. The film temperature was not controlled during exposure. Processing of the films was done in a regular photographic shop; no control was exercised on the temperature or relative humidity of the materials used in the processing. Moreover, the above two films were made for photographic purposes, not for photogrammetric applications. As a result, the only available information given with the films was the ASA of the two films.

Mathematical Models

Eight different mathematical models were used for correction of film deformation. In all of the following models, x, y are the image

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coordinates, and x, y are the reseau coordinates.

In Model I the film deformation is represented by third-degree polynomials with 20 unknowns:

$$\bar{x} = a_1 + a_2x + a_3y + a_7x^2 + a_8xy + a_9y^2 + a_{13}x^3 + a_{14}x^2y + a_{15}xy^2 + a_{16}y^3$$

$$\bar{y} = a_4 + a_5x + a_6y + a_{10}x^2 + a_{11}xy + a_{12}y^2 + a_{17}x^3 + a_{18}x^2y + a_{19}xy^2 + a_{20}y^3.$$

In Model II the film deformation is represented by second-degree polynomials with 12 unknowns:

$$\bar{x} = a_1 + a_2x + a_3y + a_7x^2 + a_8xy + a_9y^2$$

$$\bar{y} = a_4 + a_5x + a_6y + a_{10}x^2 + a_{11}xy + a_{12}y^2.$$

In Model III the film deformation is represented by a linear polynomial having six unknowns:

$$\bar{x} = a_1 + a_2x + a_3y$$

$$\bar{y} = a_4 + a_5x + a_6y.$$

The above three Models I, II, and III are commonly used for correction of film deformation in metric cameras. Model III is used if four fiducial marks are available, Model II is used where eight fiducial marks are available, and Model I is used if reseau coordinates are available.

In Model IV the film deformation is represented by a linear polynomial as in Model III, plus an odd polynomial of fifth degree. The number of unknowns in this instance is eight:

$$\bar{x} = a_1 + a_2x + a_3y + x(a_7r^2 + a_8r^4)$$

$$\bar{y} + a_4 + a_5x + a_6y + y(a_7r^2 + a_8r^4).$$

In Model V the film deformation is represented by a linear polynomial as in Model III, plus a complete polynomial of fifth degree. The number of unknowns in this case is 10:

$$\bar{x} = a_1 + a_2x + a_3y + x(a_7r^2 + a_8r^4) + x(a_9r + a_{10}r^3)$$

$$\bar{y} = a^4 + a_5x + a_6y + y(a_7r^2 + a_8r^4) + y(a_9r + a_{10}r^3).$$

The above two Models IV and V investigate whether the coefficients of lens distortion (of the total model of lens distortion and film deformation) represent lens distortion only, or a combination of lens distortion and film deformation. If any term of the coefficients of lens distortion is significant this means that the estimated values of a_7, a_8, a_9, a_{10} represent the total film deformation and lens distortion.

In Model VI the film deformation is represented by a first-degree conformal polynomial with four unknowns:

$$\bar{x} = a_1 + a_3x - a_4y$$

$$\bar{y} = a_2 + a_4x + a_3y.$$

Any film deformation in the form of Model VI will be compensated completely by the inner orientation parameters.

In Model VII the film deformation is represented by a second-degree conformal polynomial with six unknowns:

$$\bar{x} = a_1 + a_3x - a_4y + a_5(x^2 - y^2) - 2a_6xy$$

$$\bar{y} = a_2 + a_4x + a_3y + a_6(x^2 - y^2) + 2a_5xy.$$

In Model VIII the film deformation is represented by a third-degree conformal polynomial having eight unknowns:

$$\bar{x} = a_1 + a_3x + a_4y + a_5(x^2 - y^2) - 2a_6x\bar{y} + a_7(x^3 - 3xy^2) - a_8(3x^2 - y^3)$$

$$\bar{y} = a_2 + a_4x + a_3y + a_6(x^2 - y^2) + 2a_5xy + a_8(x^3 - 3xy^2) + a_7(3x^2y - y^3).$$

The above two Models VII and VIII have been introduced to investigate whether the non-linear film deformations are conformal or not.

The residual errors of film deformation in the eight different models are given in Table 1 for the ten photos using Tri-X Pan film and on Table 2 for the ten photos using Kodak Plus-X Pan film.

TABLE 1. THE RMS OF THE RESIDUAL ERRORS (IN MICROMETERS) FOR EIGHT MODELS FOR CORRECTION OF FILM DEFORMATION FOR KODAK PLUS-X PAN FILM

Photo	Mathematical Model							
No.	I	II	III	IV	V	VI	VII	VIII
1	2	2	3	3	3	5	5	4
2	2	2	3	3	3	6	6	5
3	2	2	2	2	2	6	6	6
4	3	4	4	4	4	8	6	6
5	2	3	3	3	3	7	6	6
6	2	3	3	3	3	7	6	6
7	2	2	3	3	3	5	5	5
8	2	3	3	3	3	8	8	8
9	4	4	4	4	4	7	7	7
10	3	3	3	3	3	7	6	6

TABLE 2. THE RMS OF RESIDUAL ERRORS (IN MICROMETERS) FOR EIGHT MODELS FOR CORRECTION OF FILM DEFORMATION FOR TRI-X PAN FILM.

Photo	Mathematical Model							
No.	I	II	III	IV	V	VI	VII	VIII
1	3	3	3	3	3	6	6	6
2	3	3	3	3	3	5	5	4
3	3	3	3	3	3	5	4	4
4	4	4	4	4	4	6	5	5
5	3	3	3	3	3	5	5	5
6	5	4	3	3	4	4	4	4
7	2	3	3	3	3	5	5	4
8	2	2	3	3	3	5	5	4
9	3	3	3	3	3	4	4	4
10	3	3	4	4	4	5	5	5

The results show that for both films:

- The non-linear terms of conformal Models VII and VIII and complete polynomial Models I and II are not significant. Accordingly, such non-linear film deformations are neither in a conformal form nor in a complete polynomial form.
- The lens distortion terms in Model IV and V are not significant. Accordingly, such film deformations have no significant effect on the estimated values of the lens distortion parameter in non-metric camera applications.
- In comparing all the models one can see that only Model III is the significant model.
- The linear conformal Model VI in Tables 1 and 2 gives the residual errors introduced by using Kodak Plus-X Pan and Kodak Tri-X Pan if the film deformations have been neglected in analoge and analytical photogrammetry. Any deformations in the form of Model VI will be absorbed completely by the inner orientation parameters.

Conclusions

The significance of the above results is very important for the user of non-metric cameras. The results give the characteristics of Kodak Plus-X Pan and Kodak Tri-X Pan film deformations if they are stored and developed in a commercial way. It also gives the limitation of the maximum accuracy that can be achieved by using the above two films in non-metric cameras in analogue and analytical approaches.

In the analogue approach, the maximum accuracy is limited by the residual errors obtained by Model IV. Any film deformations in the form of Model IV will be compensated completely by the inner orientation parameters of the non-metric camera.

In the analytical approach the maximum accuracy on the film plane for different models for correction of film distortion is given in Tables 1 and 2 for Kodak Plus-X Pan and Kodak Tri-X Pan, respectively.

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ORTHOPHOTO WORKSHOP III

Orthophoto workshop iii, latest in the ASP series of symposia on the state-of-the-art in orthophotography, is scheduled for June 4-6, 1975.

Sponsored by the American Society of Photogrammetry, this year's event will be held at the El Tropicano Motor Hotel, San Antonio, Texas. The Society's Texas-Louisiana Region will host the workshop.

Several new orthophoto devices have come onto the market since the last workshop and many projects are underway or now complete, in which orthophotography plays a major role.

Richard T. Church, Workshop Chairman, indicates that workshop objectives are to 1) identify the state-of-the-art, 2) provide a forum for users of orthophoto equipment, and 3) to supply the buyer or potential buyer of orthophotos a clear understanding of the fundamentals and advantages of orthophotography and its many uses.

The Third workshop is to consist of six (6) technical sessions, (two each day) during which the invited technical papers will be discussed informally, along with a limited number of unsolicited papers. According to Dr. Robert T. Turpin and Dr. Robert Baker, Program Co-Chairmen, all accepted papers will be published in a bound volume.

The Co-Chairmen have indicated that invited papers will include the fundamentals, history, recent technical progress, user procedures and project descriptions of orthophotographic endeavours.

An exhibit area including both commercial and noncommercial exhibits will be open throughout the show. Manufacturers will be exhibiting new orthophoto equipment and recent projects will be featured in the noncommercial area.

Several other national organizations are cooperating in presenting the workshop. Members will receive more detailed information on this important technical meeting at a later date.