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Methods for Studying Film Deformation

The new polyester film materials have generally reduced residual film shrinkage to less than 5 micrometers.

INTRODUCTION

THE OBJECTIVE OF the film deformation study often determines the method of investigation. Bender and Tremlett[1] have listed three general objectives; namely, the standardization of film characteristics, the standardization of film handling, and the application of *corrections* to measurements made on photographic images. The procedure for recording the film deformation and the subsequent analysis may differ in each application.

ABSTRACT: *A distinction is made between those studies that were made to determine the characteristics of film deformation as opposed to those that were made primarily to correct it. The new polyester film materials have generally reduced residual film shrinkage values to less than five micrometers. The grid method is still the most popular method for film-shrinkage investigations although the moiré pattern method is a convenient method. The subsequent correction of film deformation seems to be best accomplished with a glass reseau. The selection of the most appropriate transformation for the correction of film deformation is still open to debate. The bibliography lists 27 references.*

The film manufacturer, during the research and development of a particular film, tends to use techniques which allow him to evaluate various film types quickly without an inordinate amount of measurement requirements. A similar procedure may also be employed by the personnel responsible for standardizing the processing of film in their laboratories. The work of scientists[10,14,17] at Eastman Kodak has considered both of these objectives. Their procedures are discussed later in this paper. The majority of persons concerned with film deformation to date have been interested in not only determining the extent of film deformations, but they have also attempted subsequently to correct the deformed positions of the photographic images.

Regardless of the objectives of the film deformation study, two general sets of factors must be recognized in conducting film deformation studies.

The first set of factors are those that may lead to apparent film deformation: film flatness, film thickness, instrumental error, operator error, emulsion creep, experimental error and sampling error.

The degree to which each of these factors contributes to a film deformation study depends to a large extent on the design of the experiment. Certainly the objective in most instances is to eliminate completely these errors from the experiment. The sampling error listed here refers to the random variation that occurs in a given set of measurements on a given point. If the experiment is repeated at a later time with the same film, then this would give a basis for determining the experimental error. These types of errors are contained in most experiments and the experiment should be designed in such a manner that one can determine the magnitude of these errors, and consequently estimate the significance of the film deformation factors in view of these errors.

The second set of factors are those that may

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result in the actual deformation of the film. Ziemann[24], Calhoun *et al*[10] and others have listed these factors as follows:

- Variation in the homogeneity of the film base.
- Delayed elastic recovery of film deformation due to stretching from the film transport in aerial cameras.
- Expansions or contractions due to temperature changes, relative humidity changes, and aging.
- Distortions in the gelatin emulsion.
- Deformations resulting from the film processing which include release of built-in strain, plastic flow of base, and creeping of emulsion.

The previously mentioned objectives dictate the factors to be considered that in turn lead to the parameters for the experimental design.

Of the four universal units of length, mass, time, and temperature, only *length* has been directly utilized to gather data for film deformation studies. In all instances a given standardized length is exposed on a section of film, the film is processed, and the resulting changes in the film are noted either by a mathematical or physical matching of the film grid with the original grid.

In recent years the moiré pattern method has been introduced by Calhoun, Adelstein, and others from Kodak[10 13,14,17]. This method performs the same function as a grid, but it is more efficient.

With the previous discussion as a background, it is the intent of this paper to review a number of the past efforts in film deformation studies, and to summarize briefly the progress to date.

Past Film Deformation and Correction Studies

The review of past efforts will divide the studies into two groups. The first group deals with studies which were conducted primarily to record the nature of image and/or film deformation and the second group will include those studies that deal with either the correcting of the deformation or both the nature of the deformation as well as the correction of it.

An early study of film deformation was made by von Gruber in 1926[8]. A reseau grid was photographed and the developed copy was measured simultaneously with the original reseau in a stereocomparator. The differences between the grid on the film and the grid of the original reseau was measured with the aid of the x and y parallax screws while observing the two in the stereocomparator.

In 1946 Carman[26] made one of the first studies with aerial film in which general information was provided on the dimensional changes likely to be encountered in a survey operation. His only departure from routine conditions was the measurement of the film under constant humidity and temperature. The reference system was the four fiducial marks which were placed in modified K-17B cameras. The film distances were compared with distances determined from directly exposing a photographic glass plate. Carman concluded that scale changes between photos on a given roll could be serious unless the temperature and humidity were maintained prior and during exposure as well as during subsequent printing operations. He called for improvements over the acetate based films used in the study as well as a more efficient *squeegee* between the washing tank and the film drier.

Calhoun studied the stability of topographic aerial film in 1947[2]. His work stressed overall scale changes and the difference between values along the length of the film as opposed to across the width of the film. This comprehensive study of size changes considered humidity, temperature, processing and aging. Local or random film distortions were not considered.

In 1951 McNeil[11] reported on a film distortion study which was conducted with the aid of a glass reference grid that had been inserted into the focal plane of a CA-8 Cartographic camera. McNeil referred to the repeated emphasis on controlling exposure and processing conditions which had been called for by others. His study utilized photographs which were taken and processed under normal conditions. The residual distortions of each intersection for the 2-cm grid that had been installed in the camera was determined for two photographs. The results of the study revealed that residual film distortions could amount to as much as 30 μm. Also of interest is a similar study reported on in 1956 (Gollnow and Hagemann[3]) which resulted in distortions of 5 to 15 μm. near the edges of spectroscopic glass plates. The distortions were believed to be caused by shifts in the gelatin emulsion.

The grid method was used by Kasper and Zarzycki early in the 1950's[5] in experiments with glass plates and five film types utilizing a 19 cm$\times$19 cm-format. Mean residual distortions in the glass plates were about $\pm 3\,\mu$m and $\pm 11\,\mu$m to $\pm 14\,\mu$m in the films.

The often referred-to study of Bruchlacher and Lüder was reported on in 1956[4]. The grid method was used for this study and the standard was an 18 cm$\times$18 cm glass plate containing 63 etched intersections. The results of their studies, which were conducted on both film and glass plates, showed mean residual errors of $\pm 4.3\ \mu m$ for the film and $\pm 2.4\ \mu m$ for the glass plates. These values are remarkable considering that their measuring apparatus was an optical microscope with an accuracy of $\pm 1.8\ \mu m$. The magnitude of their errors generally did not change with age and the maximum values were mostly under $10\ \mu m$.

IN THE EARLY 1960's the grid method was employed still further by Brock and Faulds[21]. A calibrated one-half-inch grid was the control for the experiment. Two types of film were examined, one with an acetate base and the other with a polyester base. The parameters of interest were shrinkage on various portions of a single photo, shrinkage along a given film strip, and shrinkage for three different film ages. It was concluded that residual distortions tend to be slightly less along the length of the film than across the film, that residual shrinkages were similar throughout the photograph format, and that the polyester-based film should definitely be employed where non-reseau photography is utilized. In addition, the acetate-based films are not reliable if utilized immediately after processing due to the high likelyhood of moisture retention by the film base.

The question of the stability of color film was considered in 1967 and Umbach of the US C&GS* concluded that there was no significant difference in residual film deformations between black-and-white and color film[6]. Once again the grid method was utilized for the study.

Carman and Martin[25] updated an earlier study[26] by using a polyester film and a modern camera to investigate the dimensional behavior of film during routine and simulated survey operations. The usual fiducial mark dimensions were measured on each negative and compared with the dimensions obtained from glass plates exposed on the camera at 21° C. The study concludes that best results can be obtained only if the equalibrium relative humidity of the film as supplied by the manufacturer, the relative humidity at the camera, and the relative humidity at which the processed film is printed and stored are equal. To obtain the full potential from the best cameras, humidity control should be provided at the camera.

ALL OF THE previous studies have been devoted to determining the extent of film deformation and, although minor variations in methods do occur, all have generally used the grid method in some form where known distances before and after film deformation are compared.

The novel moiré pattern method was reported on in 1960 by Calhoun, Keller, and Newell[10]. In this method a halftone print on a glass plate is exposed onto the aerial film. A glass plate made from the processed film is then registered with the glass master positive and a scale change registers as a pattern of moiré dots. This also provides a convenient method for the detection and measurement on aerial film negatives any local distortions, which are displayed as irregularities in the moiré pattern formed. Quantitative measures of these irregularities can be made by using a microdensitometer and automatic data-processing equipment. Calhoun *et al* used a halftone pattern with about 83 dots per centimeter and they state that the limit of detectability using this pattern is about $3.8\ \mu m$. The factors studied during this effort were the effect of water spots, the effect of excessive heat on the film, and the effect of high tension in the processing machine.

A further study utilizing the moiré pattern method was reported on in 1961 by Calhoun, Adelstein, and Parker[13]. The subject of the measurements in this case was the polyester films whereas the previous studies concentrated on the acetate films. This is a significant report on the properties of Estar polyester-base aerial films which have presently gained such wide usage. The study concludes that Estar polyester films give advantages in strength properties, flatness, and dimensional stability.

In 1963 Adelstein and Leister utilized the moiré pattern method in studying nonuniform dimensional changes in topographic aerial films[14]. The precision of the procedure was limited by the 300 line-per-inch halftone pattern which was employed. This was the finest halftone pattern available that met the standards for pattern uniformity. Therefore, in order to improve the precision of this system, the halftone print from the film was registered with a master halftone which had a slightly different scale. This created a greater number of moiré dots, and therefore more sample distances could be measured on each piece of film. This modification of the moiré-pattern method displayed shrinkage values to ± 0.002 percent for distances down to 2 to 3 inches. Further local distortions would show up as density variations in the moiré patterns[14]. The results of this study showed that the polyester film has less variation along the film roll than

* The name of the organization has since been changed to the National Ocean Survey.

acetate film and that processing variations are less when using the polyester film. The importance of adequate film drying with respect to the moisture equilibrium was once again shown.

A fourth study on film deformation using the moiré pattern was reported in November 1966 by Adelstein, Josephson, and Leister[17]. Using the methods previously described, the dimensional changes for the acetate- and polyester-based films were determined from film processed in six commercial laboratories. Improved methods were used in the data reduction; and the parameters of length change, width change, diagonal change, and average relative vector displacements were determined for each exposure studied. Differences in the film deformation seemed to be related mostly to incomplete drying of the film in the laboratories before the printing of the glass plates which were subsequently returned to Kodak for evaluation. Once again the polyester base showed an improved performance over the acetate based film.

THE STUDY by Moren in 1967 entitled "The Geometrical Quality of Aerial Photographs" shows interesting residual distortion plots for the polyester and acetate films[7]. The work of four researchers were summarized and the results were quite similar for both types of film. The residual errors were smaller for the polyester film but it had displayed a lack of orthogonality in the past.

Many studies have been conducted in which the primary concern is to correct for film deformation assuming that it is present. In some instances, as was previously recalled, the image deformations only seem to be film deformations. For all applications, where the study was purposely conducted to correct image deformations, a grid reference system of some type was used. This is only natural as the image coordinate system itself is a type of grid system. Even photogrammetric plotters utilizing a scale change to correct for film deformation obtain this information from the grid-like fiducial system. The reference grid, as detailed in a recent paper by Ziemann[24] can be exposed with the photograph, before the photograph is taken or after the photograph is taken. In each event the grid will capture certain deformations.

In 1958 Sadler[9] discussed placing a reseau in the focal plane. He states that such an arrangement would virtually eliminate all of the error effect of film shrinkage.

Tewinkel summarized the methods of correction used by the US C&GS in 1960[20]. In this instance the four corner-located fiducial marks are projected onto the film at the instant of photography. Using the normal data collecting methods three types of compensation equations are used, namely translation, rotation and scaling, and a hyperbolic transformation in order to fit the distorted fiducial positions to calibrated positions. Tewinkel stated that residuals of up to 20 μm remained after this procedure, but he estimated that this will be reduced to 5 μm when the polyester base film is introduced.

Harris[12] reported in 1962 that the US C&GS's largest residual errors are probably those of film distortion. Using grid techniques, regular checks were made to determine the residual distortion that existed in their operations. First a uniform scale change was made to determine residual errors in the model formed in the stereoplotter during map compilation and, secondly, the data were treated with an analytic non-affine transformation to determine the residual film distortions that were propagated through the strip or block. It was recommended that eight fiducial marks be used for analytic photogrammetry purposes. Their experience being that the 8 fiducials resulted in one-quarter the residual film distortion that the 4 fiducials produced, and that the eight fiducial marks provided local control of film distortion in the model pass-point area.

In 1965 Trachsel published an article in which an interesting reseau technique was discussed[15]. In lieu of not having a reseau in the camera a scribed reseau is superimposed on the copy negative prior to mensuration. For a given camera, corrections for film shrinkage etc. can be incorporated into the reseau calibration. The subsequent adjustment of the calibrated reseau to the measured reseau will correct for translation and rotation between the comparator and photographic reference system. This has been referred to as segmented mensuration. This technique can materially increase the accuracy of coordinate measurements on enlarged sections of small-scale photography.

FURTHER WORK of the US C&GS was reported on in 1965 by Lampton[16]. The tests discussed in this paper once again showed considerable improvement if 8 fiducials were used instead of 4 corner fiducials. A hyperbolic transformation was used with the four fiducials, providing a unique solution. A higher-order transformation was used for the 8 fiducial system which also provided a unique fit. A standard residual error of 4 μm over the entire photograph resulted through the use of the 8 fiducial system and the corresponding correction equations.

The US C&GS followed this work by a report on "Film Distortion Compensation Effectiveness" in 1966; the authors of this work were Lampton and Umbach[18]. The study used three transformations to evaluate shrinkage via the usual grid technique. The first was a similarity transformation which closely simulates the conditions in an analogue plotter. Eighteen film samples were used and in each instance the transformation was used to fit the measured and calibrated positions of four corner fiducial marks. The average residuals for a 206-point reseau were approximately 10 μm. The linear adjustment was also applied to the simulated positions of 9 pass points and the average residual error was 5.7 μm for this arrangement. The non-affine or hyperbolic transformation was also applied to a similar pass-point configuration and this resulted in an average residual of 5.5 μm.

In addition, a higher-order transformation was fit to 8 fiducials and the residuals were calculated for the remaining points. The superiority of the 8 fiducial system was demonstrated. Finally, the optimum spacing for reseaus was investigated and it was found to be about 2 cm as improvements found in more closely spaced reseaus would be lost in the noise level of the measurements.

Blachut[27] reported on an interesting experiment in 1966 to determine the effects of film shrinkage on instrumental triangulation. The relative and absolute orientation of grid models were performed along a strip of film. The results found for glass-negative-to-glass-plate diapositives was more than three times better than the values obtained from film-to-glass-plate diapositives. The relatively large errors for the film were thought to be due to the fact that almost half of the measured points were located along the edges of the models where the effects of film shrinkage would be strong. Blachut refers to the fact that reseau photos necessitate a great amount of work and are of no help in conventional plotting; consequently they appear to be only a partial answer to problems. As film deformation seems to be the limiting factor, the use of plastic plates instead of the roll film was suggested.

Bender and Tremlett[1] published an interesting paper in 1967 in which the measurements from the Brock and Faulds study[21] were processed with five different transformations, namely, the similarity, affine, projective, hyperbolic and a higher-order transformation. The study concluded that eight fiducial marks provided a significant improvement over four; and, if four fiducials are used through necessity, the projective and hyperbolic transformation can not be relied on to give a better fit than the affine. The high-order transformation generally gave better results than the other transformations listed above.

Ziemann of the National Research Council of Canada reported on trials to correct the film deformation in 1967[22]. Four transformations were used including linear conformal, linear affine, a second-degree polynominal and third-degree polynomial. The best results were obtained with the third-degree polynomial with the average residuals ranging from 1 to 2 μm. The input coordinates were the averages for 9 photos, each photo containing 49 reseau points.

An operational calibration of the aerial photographic system was conducted by Merchant and reported on in 1967[23]. A reseau register camera was not available and therefore a reseau was pre-flashed onto the photography before the photo mission. Kodak film type 5401 was used for the experiment. Analysis of the results indicated that the large residuals for image points were probably a result of humidity differentials occuring between the pre-exposing of the reseau and the taking of the photography. In order to reduce this type of error a reseau bonnet is proposed which would enable a reseau to be pre-exposed on the film just moments before the actual photography.

A recent article by Ziemann is entitled "Is the Request for Eight Fiducial Marks Justified?"[19]. The main variables in this study were the arrangement of the fiducials or reseau marks and the transformation that was used to correct for image deformation in each case. Photographs from as many as 14 missions were sampled for the computations. The study indicated that, as long as the fiducial marks are evenly distributed, the distance between the fiducial marks and the center of the photograph is more important than their direction with respect to the center of the photograph. Because of this, equally weighted fiducials marks located in the corners, which are part of the eight fiducial mark system, do not provide an effective image deformation correction if conventional transformations are used and points are distributed over the entire format. Eight fiducial correction systems do provide advantages if the corner fiducials are located or weighted properly. A proper reseau correction proved to be more effective than any of the eight-fiducial mark arrangements apparently because the fiducial marks located along the edges of the photograph are not able to account for local deformations within the photograph. Ziemann concluded that the projective equation performed generally best.

Ziemann gave in "Image Deformation and Methods for its Correction" a particularly unique definition of image deformation; different types of reseaus were discussed, correcting for different groups of errors[24]. Practical tests were conducted using the reseaus at different stages in the photogrammetric process. In addition studies were conducted with different correction methods and utilizing different fiducial constraints and reseau densities. Ziemann recommends using a reseau at its highest resolution.

Summary

The new polyester film materials have generally reduced residual film shrinkage values to less than 5 μm. In addition, they deform less from temperature and humidity, tend to be flatter, and are very strong.

The grid method is still the most popular method for film-shrinkage investigations mainly because it allows a rather exact and natural correction to be made to the image coordinates.

The moiré pattern method is a convenient method for studying film characteristics and for routine quality-control checks.

The subsequent correction of film deformation seems to be best accomplished by a glass register reseau. There is some reluctance to use the reseau photography for analogue techniques and some photogrammetrists still feel that the little improvement gained by the reseau is hardly worth the additional effort and cost involved in its use. An efficient reseau configuration has yet to be developed.

The selection of the most appropriate transformation for the correction of film deformation is still open to debate; however the higher-order transformations seem to be preferred by most.

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