The calibration of aerial survey cameras

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The authors are members of the Division of Metrology, National Standards Laboratory, C.S.I.R.O., Sydney. *This report describes the methods used at the National Standards Laboratory for the calibration of aerial survey camera optical units.*

Introduction

The optical unit of an aerial survey camera consists essentially of the lens with its associated diaphragm, shutter, filter and the film-registering surface. The lens and film-registering surface are rigidly connected so that once the camera has been adjusted no relative movement should take place between them during the subsequent use of the camera.

In the film-registering surface there are certain fiducial marks, an image of which appears in every photograph which is taken with the camera. These may be, for instance, crosses ruled at the centre, the four corners and the mid-points of the four sides of a register glass, or they may be light patterns projected on to the emulsion surface by small subsidiary optical systems at the four corners of the registering surface.

The complete examination of a photogrammetric camera would include the determination of the resolving power of the lens, the position of the principal point of autocollimation, the calibrated focal length, the distortion characteristics, and the co-ordinates of the index markers on the register glass or on the body.

The examination of cameras at the National Standards Laboratory includes only the determination of the location of the principal point of autocollimation, the calibrated focal length, and the distortion characteristics. It is considered that no demand is likely to be made for measurements of resolving power of the lens, as no survey cameras are manufactured in this country, and a lens for any camera intended for precision photogrammetry should be accepted from overseas only if supplied with a certificate from a recognized institution giving the resolving powers under specified conditions.

In the case of cameras fitted with a register glass, replacement register glasses are usually accompanied by a report from the maker stating the thickness of the glass and the co-ordinates of the index marks on it.

Location of the Principal Point of Autocollimation

The principal point of autocollimation of a camera is that point in the film-registering surface which is coincident with its image formed by reflection in a plane mirror in the object space, the mirror being accurately parallel to the film-registering surface. This is equivalent to saying that the principal point of autocollimation is the point where a parallel beam of light in the object space, perpendicular to the film-registering surface, is brought to a focus in the surface.

The principal point of autocollimation is readily located by the methods to be described, and its distance from the centre fiducial mark on the film-registering surface can be rapidly and accurately determined. Therefore, the determination of the position of the principal point of autocollimation affords a rapid means of ascertaining whether any changes have taken place in a camera since its previous calibration.

The position of the principal point of autocollimation is found by mounting the optical unit of the camera in a levelling stand with the lens pointing down. Immediately below the lens is a vessel of about four inches diameter containing some clean mercury.

A sensitive bubble is placed on the film-registering surface, and the level of the camera is adjusted until the film-registering surface is shown by the level to be accurately horizontal, that is, it is parallel within two seconds to the surface of the mercury in the vessel below the lens.

A low-power measuring microscope (magnification ×30), with a vertical illumination, is mounted above the film-registering surface and focused on a suitable target in the surface. In the case of a camera equipped with a register glass the target is the centre cross marked on the glass. In the case of a camera not fitted with a register glass a target could be used which relates the principal point of autocollimation to the index markers on the camera body.

The microscope is focused and adjusted so that the centre cross appears in the middle of the field. The image of the cross formed by autocollimation in the surface of the mercury will also appear in the field, and if the separation of the centre cross and its image exceeds 0·02 mm., the camera is adjusted to reduce the separation until it is within this value. The centre cross then determines the position of the point of autocollimation within 0·01 mm.

Determination of Calibrated Focal Length and Distortion Characteristics

The calibrated focal length is determined by a method similar to that of Deville (1895) in which a precision scale ruled on glass and graduated in centimetres is fixed to the register glass of the camera. The scale carries also two parallel lines perpendicular to the length of the graduation lines.

The optical unit is set up over the mercury pool with the register glass horizontal and the scale placed along one diagonal of the register glass. The position of the scale is adjusted so that the two long lines normal to the graduations, and a suitable graduation line (16 cm.) and their images formed by reflection from the mercury pool, are coincident. The scale is held in close contact with the register glass by means of two weights placed on it, one near each end, and is fixed to the register glass with cellulose acetate cement. The contact of these is checked for uniformity and magnitude by examination of the interference fringes between them.

When the cement is set and the scale firmly attached to the register glass, the optical unit is placed with its axis and the scale in a horizontal plane on a levelling mount on the top of a heavy concrete pillar. The level of the mount is adjusted until the scale and the optical axis are accurately horizontal. A fluorescent lamp, with the tubes parallel with the scale, is set up immediately behind the optical unit and illuminates the scale.

The angle in the object space, corresponding to each graduation line on the scale, is measured by a one-second theodolite mounted on a horizontal track on another concrete pillar in front of the optical unit.

A collimator mounted on a third pillar in line with the track carrying the theodolite provides a reference line for the measurement of angles with the theodolite. A plan view of the equipment is shown in Figure 1.

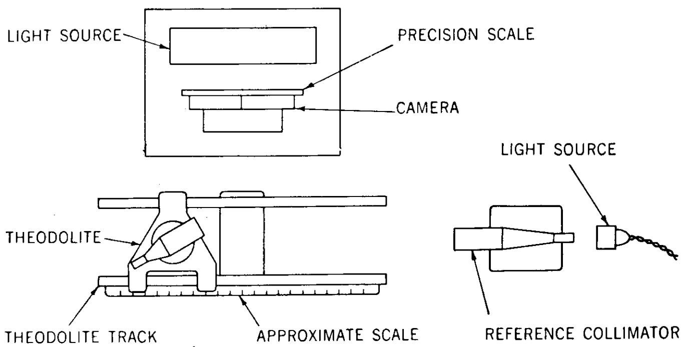


Fig. 1

The theodolite is placed in the centre of the track approximately in line with the optical unit, and is levelled. Readings are made on the vertical cross-wire of the collimator and on the centre graduation of the scale.

The theodolite is moved to the right along the track until it is aligned on the next division of the scale. Its level is checked and the same sequence of settings and readings made. This procedure is repeated for all the graduation lines on the scale and a second independent series of observations is made.

An index mark on the theodolite carriage indicates on a scale fixed to the track and enables the theodolite to be correctly positioned for each graduation on the glass scale.

The scale is then removed from the register glass and remounted along the other diagonal, and the whole procedure repeated for the second diagonal.

Reduction of Results

Let θ_n be reading on scale for nth line.

ϕ_n be the corresponding reading on the reference line.

α_n be angle emergent beam at nth line makes with axial beam.

d_n be distance of nth line from the centre line.

f be calibrated focal length.

v_n be the radial distortion at nth line.

Let $\theta_n - \phi_n = \gamma_n$

and $\gamma_n - \gamma_o = \alpha_n$

Then (Fig. 2) $v_n = f \tan \alpha_n - d_n$

The values of γ_n are computed for each value of θ_n and ϕ_n and from these are derived the values of α_n for each line of the scale.

There are various techniques for determining f from the known values of α and d in each quadrant. The method of most general application is probably to use the technique of least squares and obtain the value of $\bar{f}$ for which Σv_n^2 is a minimum.

Now

$$\Sigma v_n^2 = \Sigma (f \tan \alpha_n - d_n)^2$$

and by differentiation $\bar{f} = \dfrac{\Sigma d_n \tan \alpha_n}{\Sigma \tan^2 \alpha_n}$

Alternatively it may be required to obtain a calibrated focal length such that the distortion curves passes through two specified points, one being the origin (0, 0) and the other (α_s, v_s). The calibrated focal length f_s may be obtained directly from the observations or from the value of $\bar{f}$ obtained by least squares—

$$\bar{v}_s = \bar{f} \tan \alpha_s - d_s$$

$$v_s = f_s \tan \alpha_s - d_s$$

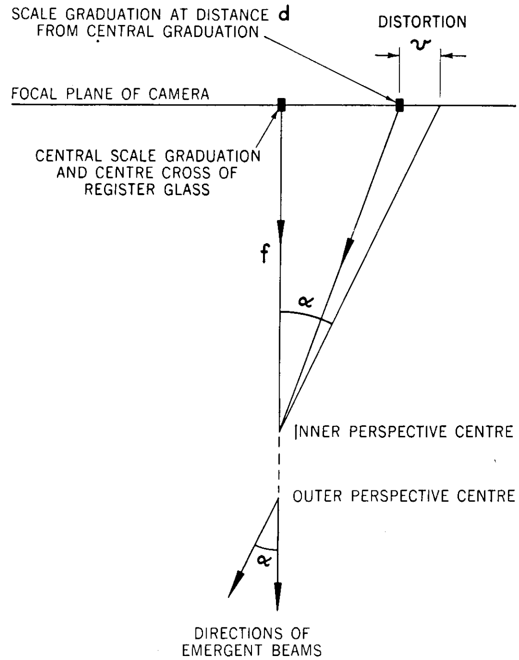
Whence $f_s = \bar{f} + \dfrac{v_s - \bar{v}_s}{\tan \alpha_s}$

The appropriate values of f_s having been obtained for each quadrant, the distortion at each point is readily computed from the known values of f_s and d.

It should be remarked that all angles are taken to the nearest second, all lengths to the nearest micron (0·001 mm.), and eight-figure tables are used throughout the computations.

It frequently happens that the values of f obtained for each of the four quadrants differ significantly, and a mean value has to be taken for f. This results in distortion curves which are non-symmetrical for each diagonal and not necessarily the same for the two diagonals.

The physical interpretation of this phenomenon is that the point taken as the origin for distortion measurements, that is, the principal point of autocollimation, is not coincident with the point about which the distortion happens to be symmetrical. This lack of coincidence is generally attributed to decentering of one or more components of the lens (Hotine, 1929), which produces an effect equivalent to placing a prism in the system. The phenomenon is generally known



IF THE INNER PERSPECTIVE CENTRE IS TAKEN AS LYING ON THE PERPENDICULAR TO THE FOCAL PLANE THROUGH THE CENTRAL SCALE GRADUATION, THEN $v = f \tan \alpha - d$.

Fig. 2

as "prism effect" (Washer, 1941). An analysis has been made of this problem and rapid tabular and graphical methods have been developed for computing the displacement of the point of symmetry from the principal point of autocollimation (Mayer, 1957).

Discussion

It has been suggested (Howlett, 1950) that the visual technique used in the measurement of the calibrated focal length and distortion is not entirely satisfactory, as it does not reproduce the conditions of use of the camera, and that a photographic technique should be used. If the calibration were made simultaneously with a test of resolving power, as is done, for example, by the National Bureau of Standards (Washer and Case, 1950), it would be necessary to use a photographic method.

However, as was stated in the introduction, it is not considered necessary to carry out tests of resolving power at this laboratory. For the measurement of calibrated focal length and distortion, the visual is considered more satisfactory than the photographic method, in that it does not introduce uncertainties due to grain and to possible dimensional changes in the emulsion during processing.

It may be argued that the differences between the colour sensitivity of the eye and of a photographic emulsion combined with the chromatic aberrations of the lens may lead to a difference in the values of the calibrated focal length obtained by visual and photographic methods. Three calibrations of the same camera, made with red, green and blue filters respectively, did not show any significant variations in the calibrated focal length. It is considered, therefore, that the results of visual and photographic calibrations will not differ significantly, particularly as the calibration is usually made in conjunction with the filter with which the camera is used.

There are other possible sources of systematic errors, including errors in the scale, in the mounting of the scale, in the theodolite scale and in the position of the theodolite, that is, the error introduced by the theodolite not being directed at the front nodal point of the lens.

The glass scale has been compared with laboratory standards of length and the intervals of the scale are known within 0·001 mm. Also, a series of measurements were made on a camera in which observations were made with the scale in its normal position and then with the scale rotated in its own plane through 180°. The results of these two sets of measurements were closely identical.

Repeated measurements, between which the scale was removed and reset on the camera, yielded no significant variations, thus showing that the method of mounting the scales is satisfactory in so far as the calibration figures are not affected.

A selection of points on the theodolite scale has been checked and the errors found not to exceed four seconds. In addition, a series of calibrations were made on a camera during which different sections of the theodolite scale were used. Again there was no significant difference between the results.

The question of random errors has also been investigated along the following lines.

The distortion v_n is given by the equation

$$v_n = f \tan \alpha_n - d_n$$

whence $$\Delta v_n = f \sec^2 \alpha_n \,.\, \Delta \alpha_n$$

$$\Delta \alpha_n = \frac{1}{f} \cos^2 \alpha \,.\, \Delta v_n$$

The values of $\Delta \alpha_n$ for $\Delta v_n = 0{\cdot}005$ millimetre and $f = 150$ millimetres are given in Table 1.

TABLE 1

Values of $\Delta\alpha_n$ for $\Delta v_n = 0{\cdot}005$ mm., $f = 150$ mm.

α_n degrees	$\Delta\alpha$ seconds
0	6·9
10	6·7
20	6·1
30	5·2
35	4·6
40	4·0

It is apparent from the values for $\Delta \alpha_n$ in Table 1 that there is a good margin for safety up to the 40° zone, as the discordance between duplicate values of α rarely exceeds two seconds and the discordance between values of α obtained from the independent settings rarely exceeds three seconds. A further check on the absence of random errors of any magnitude is afforded by the small departures of the observed points from the smooth curve of best fit for these points.

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