Simple Cameras for Close-Range Applications

Acceptable accuracy can often be achieved with some of the better non-metric cameras.

INTRODUCTION

Since the early days of photogrammetry, photogrammetrists have attempted to extend the application of the technique beyond the field of topographic mapping which continues to be the principal area of application of photogrammetry.

Most of the non-topographic applications of photogrammetry have been in the close-range†, and the terms close-range photogrammetry and non-topographic photogrammetry were interchangeably used and associated with photogrammetric measurements in such diversified fields as animal husbandry, anthropometry, archeology, architecture, criminology, deformation of objects, hydraulics, hydrology, structural testing, tailoring, traffic accident investigations, nuclear physics (measuring bubble chamber photographs), aerodynamics, medicine, dentistry, bacteriology, and material science, etc.

With the exception of the application in traffic accident investigation and architecture, which have been in regular use (mainly in Europe) for a few decades, most of the above listed applications have been, in general, experimental in nature. Even though such experiments have proven the potentiality and usefulness of photogrammetry as a measuring tool in these disciplines, the widespread application of this technique in most of these fields has not gained general acceptance.

The main reason for this unfortunate situation seems to be the rather high degree of heterogeneity in conditions and requirements of the various applications. The few commercially available photogrammetric cameras (single cameras, stereometric cameras, phototheodolites, etc.), although extremely well suited for the applications for which they were designed, are simply not capable of meeting the wide range of requirements of applications in an increasing number of fields mainly be-
cause of their rather restricted range of focus. Furthermore, applications involving unstable platforms and those requiring quick successions of photographs are obviously not suitable for currently available photogrammetric cameras.

It is not economically justifiable for photogrammetric camera manufacturers to offer as many different types of metric cameras as would be necessary to cover the wide spectrum of requirements of the various applications of close-range photogrammetry. As Schwidelsky14 puts it, "we have a vicious circle; photogrammetry is not applied in many cases, no appropriate metric cameras being on the market; and because of insufficient rate of sale the design of new camera types is not stimulated."

Under these circumstances, it became clear recently that if photogrammetry is to be applied on a broader scale than is currently the situation, the possibility of the use of non-metric cameras must be thoroughly investigated. Concentrated research efforts are currently underway in numerous centers all over the world, and available results indicate that such an approach seems to be very promising.

NON-METRIC CAMERAS

ADVANTAGES

Among the most attractive features of non-metric cameras are:

* General availability.
* Flexibility in focusing range, particularly with the availability of interchangeable lenses.
* Some are motor driven, allowing for a quick succession of photographs.
* Can be hand-held and oriented in any direction.
* Price (considerably less than for metric cameras).

DISADVANTAGES

Among the major disadvantages of non-metric cameras:

* The lenses are designed for high resolution at the expense of high distortion.
* Most of the simple* cameras operate with film of small format (standard sizes 2.5X2.5 inches, 36X24 mm) which has a questionable dimensional stability particularly because no flattening mechanism is used. (Where professional cameras of the Graphflex type are used, there is the advantage of the larger format, the possibility to use glass plates instead of film, but the disadvantage of an unknown interior orientation).
* Most non-metric cameras have a variable principal distance which in general changes at each principal distance setting, thus affecting the interior orientation.
* Lack of fiducial marks in most non-metric cameras (a late Hasselblad model—El Data—which incorporates a reseau).
* The absence of level bubbles and orientation provisions precludes the determination of the exterior orientation before exposure.

OVERCOMING THE DIFFICULTIES OF NON-METRIC CAMERAS

Concentrated research efforts, pioneered by the late Professor Hallert and his group, as well as studies at various universities including Karlsruhe, Stuttgart and Illinois have clearly shown that, in spite of the critical disadvantages of non-metric cameras, such cameras can be used in precise close-range photogrammetric work provided that:

1. Cameras are calibrated appropriately. Among the suitable calibration methods are those developed by Brown, Hallert, Torlefgard, Harley, Jacobi, and Dohler. Depending on the stability of the interior orientation of the camera, it is necessary in some applications to calibrate each photograph.
2. Use of sufficient object-space control data (target coordinates, distances, directions, etc.).
3. Use of the analytical approach in data reduction. A method particularly suitable for non-metric photography was recently developed at the University of Illinois, and is briefly outlined later.

Through the use of these precautions, the instability problems in interior orientation of non-metric cameras can be overcome to an appreciable degree, and simple cameras become a most reliable data-acquisition tool capable of achieving the same order of accuracy reached through photogrammetric close-range cameras. A case in point is Döhler's report on recent experimental research where he used on one hand three non-metric cameras (Hasselblad 500-C, Robot Recorder 36 ME, and Linhof Technika), and on the other hand two photogrammetric cameras (Jena Phototheodolite 19/1318, modified for 4.5 meters object distance; and a Zeiss SMK-120 Stereometric camera equipped with lens attachments to reduce its minimum focussing distance to 2.5 meters). The results achieved by Döhler and researchers in other centers leave no doubt about the photogrammetric potentials of simple cameras.

It should be pointed, however, that because of the rather large lens distortions in most non-metric cameras, the use of the analogue approach in data reduction from photography
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taken by such cameras is not feasible if precise results are needed. The use of computer graphics in conjunction with an analytical data reduction provides a possible solution for compiling maps in this instance. Concentrated research is currently underway on the possibilities of using stereoplotters in this connection, but the problem seems to be far from solved at this time.

OUTLINES OF A METHOD PARTICULARLY SUITABLE FOR DATA REDUCTION OF NON-METRIC PHOTOGRAPHY

In the usual application of analytical photogrammetry, the transformation of comparator coordinates into object space coordinates is usually performed in two steps:

- Transformation from comparator coordinates into image coordinates, and
- Transformation from image coordinates into object space coordinates.

For the transformation from comparator coordinates into image coordinates, it is necessary to calibrate and measure fiducial marks. For the transformation from image coordinates into object space coordinates, an iterative solution is generally used for which one needs initial approximations for the unknown parameters (elements of outer orientation and in some instances also elements of inner orientation of the camera). In working with hand-held non-metric cameras, neither of the above two requirements are satisfied.

A method for data reduction which overcomes these difficulties has been recently developed at the University of Illinois\(^1\). This method involves a direct linear transformation from comparator coordinates into object space coordinates. In a sense, it is a simultaneous solution for the two aforementioned transformations. As the image coordinate system is not involved in the approach, fiducial marks are not needed. Furthermore, the method is a direct solution and does not involve initial approximations for the unknown parameters of inner and outer orientation of the camera.

This method is thus particularly suitable for the reduction of data in non-metric photography. As applied to metric photography, the proposed approach yields at least the same accuracy as the conventional methods, but is easier to program (no linearization necessary) and uses less computer memory and executing time.

The basic equations used in this method are:

\[
\begin{align*}
x + \Delta x + \frac{l_1 x + l_2 y + l_3 z + l_4}{l_5 x + l_6 y + l_7 z + l_8} &= 0, \\
y + \Delta y + \frac{l_9 x + l_{10} y + l_{11} z + l_{12}}{l_{13} x + l_{14} y + l_{15} z + l_{16}} &= 0,
\end{align*}
\]

where \(x, y \) are the comparator coordinates of an image point, \(X, Y, Z \) are the ground coordinates, \(l_1, l_2, \ldots, l_{16} \) are the transformation coefficients, and \(\Delta x, \Delta y \) are the errors due to lens distortion and film deformations, the mathematical modeling of which by power series involves at least three coefficients, \(a_1, a_2, a_3\).

The number of unknowns in this case is 14: \((l_1, l_2, \ldots, l_{11}, a_1, a_2, a_3)\). From the knowledge of at least 7 control points and their comparator coordinates, the 14 unknowns can be determined. Redundant control is, of course, highly recommended.

Full details about this method are given in Reference 1. Currently under investigation is the adaptation of the approach used by Brown\(^2\) in his plumb line method into the direct linear transformation approach. In this fashion, the object-space control would include a series of directions and distances rather than points of known spatial coordinates.

SOME EXAMPLES OF ENGINEERING APPLICATIONS

AUTOMOBILE SPEED CONTROL\(^6\)

Hallert\(^6\) reported on a traffic control system, called Traffipax, in which the Swedish police uses a Robot motor-recorder camera for checking the speed of vehicles on straight stretches of the road. The car whose speed is being checked is photographed from a police car behind it, with the camera axis closely parallel to the direction of movements of the two cars. Photographs are taken through the windshield and are repeated at certain time intervals. In the photographs, the speedometer of the police car and a chronometer are also projected and imaged together with the rear of the car under surveillance. The time interval between exposures is normally about four seconds. The basic principles of the procedure are shown in the following Figure 1.

A distance \(a\) (for example between the rear wheels or between the rear lights of the car under surveillance) is imaged as \(x'_1\) in the first exposure where the object distance is \(d_1\). In the second exposure (object distance \(d_2\)) the same distance \(a\) is imaged as \(x'_2\). If the distances \(d_1\) and \(d_2\) are different, the image distances \(x'_1\) and \(x'_2\) will be different. If the negative plane and the distance \(a\) are parallel
in both exposure moments, if the camera constant \( c \) is known and if the pencils of rays are mathematically correct, the distance difference \( \Delta d \) can be calculated from the simple expression

\[
\Delta d = x \cdot c \cdot [(1/x_1') - (1/x_2')].
\]

The speed variation during the interval between the two exposures can then be calculated from the expression

\[
\Delta v = \frac{\Delta d}{\Delta t}
\]

where \( \Delta v \) is the speed change and \( \Delta t \) the time interval between the exposures.

The standard error of the speed difference \( \Delta v \) can be computed as:

\[
s_{\Delta v} = s_{\Delta d} \left[ \frac{1}{x_2'} \left( \frac{s_{x_2}^2}{x_2'} \right) + \frac{1}{x_1'} \left( \frac{s_{x_1}^2}{x_1'} \right) + \left( \frac{s_{\Delta d}}{\Delta d} \right)^2 \right]^{1/2}
\]

The system was calibrated under real operational conditions (photography through the windshield) using the well-known calibration methods developed by Haller. A stereocomparator was used for measurements. Under typical conditions, the standard error of the speed variation is reported to be 5 percent of the variation itself. Such an accuracy is quite acceptable for legal evidence.

**DIGITAL MODELS FOR HYDRAULIC SCALE MODELS**

In hydraulic engineering laboratories scale models of waterways and structures are often used to determine the optimum shape of structures and the alterations that are necessary to influence the current in the waterway. The resulting configurations are then measured in the scale model and implemented in the hydraulic system. Digital models are a very efficient tool in connection with adaptation of experimental lab findings to existing structures. As indicated by Schwidetsky, digital models (of the scale model of structures) can be adapted by mathematical transformation to a photogrammetrically produced model of the existing structures.

Schidetsky reports on the photogrammetric scheme used to measure a scale model (1:29) of a barrage used in a hydraulic laboratory to find the optimum shape of two outlet troughs. A Linhof Technika camera was mounted on a light platform below the ceiling. The photographs were taken downward. An aperture of \( f/22 \) was used because of depth of field problems. Two 1500 W lamps were used for illumination. The photographic scale ranged between 1:10 and 1:17, and the base-to-height ratio varied from 1:7.5 to 1:12.5.

**DETERMINATION OF THE SHAPE OF THIN SOAP MEMBRANES**

Thin soap membranes are used as analogue models to solve certain design problems in architecture and structural engineering. Faig determined photogrammetrically the shape of a membrane which represented the roof of the German Pavilion at the Montreal 1967 World Fair to an approximate scale of 1:400. The camera system consisted of two glass-plate Sinar-Norma 13×18-cm cameras whose back frames were modified by adding four fiducial marks and a pressure device to press the glass plates against the plane of the fiducials. Two Schneider \( f/8 \), 90-cm Super-Angulon lenses were used. The cameras were calibrated thoroughly before taking the photographs. The object distance was about 1 meter and the base was chosen as 30 cm. The photo scale was approximately 1:10. Data reduction was done analytically using a Jena 1818 stereocomparator for measurements. An accuracy analysis of the system was conducted using a sphere. The standard errors in coordinates of object-space points amounted to 0.11 mm in the direction of the parallel photographic axes (y), and were 30 to 50 percent smaller in the other two perpendicular directions (x and z). The results
were considered very satisfactory for structural design purposes.

MEASUREMENT OF ROAD SURFACE TEXTURE

Sabey and Lupton\(^1\) used a simple specially built single-lens bellows camera which was housed together with flash equipment in a wooden box measuring 14 X 16 X 18 inches. An f/6.8, 9-cm Schneider Angulon lens was used. The lens apertures used were between f/32 and f/45 to ensure that the depth of focus (slightly more than 1 1/2 inches) covers both hills and valleys on the majority of road surfaces measured. Two horizontal plates (4.25 X 3.25 X 0.25 inches) were used, and the lens assembly could slide horizontally to record a stereopair of the area of the road surface. Sufficient vertical movement was incorporated to allow focussing. Base-to-height ratio was kept between 1:2 and 1:10. Simple parallax equations were used for data reduction, and a comparagraph was used for parallax measurement. The internal precision of determination of height differences was reported to be ±0.01-inch standard error. The final output was in the form of profiles which were used to assess features of the road surface.

A project along the same lines is currently under consideration by the Highway Engineering Group of the University of Illinois. A 2.5 X 2.5-inch format film camera is to be used and each photograph will be calibrated through a simple three-dimensional control arrangement incorporated in the box housing the camera and flash equipment. The direct linear transformation approach\(^1\) would be used for data reduction.

CONCLUSIONS

All indications are that non-metric cameras will play an important role in future expansion of close-range photogrammetry and in its general acceptance as a measuring tool in a wide spectrum of disciplines and fields. Although experimental research has so far concentrated on better non-metric cameras (Hasselblad, Rolleiflex SL, Robot, Linhof Technika, etc.) and proven their photogrammetric worthiness, it is anticipated that less elaborate cameras can be used particularly in applications with medium and low accuracy requirements. This matter is currently under investigation at the University of Illinois.

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REFERENCES


