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AERIAL PHOTOGRAPHY FOR REGIONAL SURVEYING AND MAPPING

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AERIAL PHOTOGRAPHY FOR REGIONAL SURVEYING AND MAPPING[1]

ABSTRACT

Improvements in photographic and photogrammetric instrumentation and in data reduction techniques, during the past few years, have resulted in evidence that aerial photogrammetry now has the potential accuracy required for the establishment of geodetic control adequate for large-scale mapping in sparsely controlled areas where a basic network of geodetic stations with a spacing of approximately 300 kilometres can separately be established through photogrammetric observations of passive sunlit satellites.

The paper describes investigations and experiments towards the refinement of aerial photogrammetric methods to make the aerial camera a reliable geodetic tool. The goal of this effort has been to seek out sources of systematic errors, to determine their magnitude and to make compensation for them through the use of mathematical expressions.

The success of this and other programmes has led to the conclusion that ultra-precise aerial photogrammetry has great potential value when used at very high altitudes. The use of satellites and very high altitude aircraft as camera platforms is considered expressing the auxiliary data requiresments for each method and estimating their resulting accuracies in metres on the ground.

Some of the important characteristics of aerial cameras are defined with respect to photographic resolution and metric fidelity. The use of colour films is recommended for improved photographic resolution and additional information content. The recommended approach appears to be of general interest to precision aerial triangulation regardless of flying height or photographic scale.

1/ By William D. Harris, Research Engineer, Office of Geodesy and Photogrammetry, Coast and Geodetic Survey, Environmental Science Services Administration, US Department of Commerce.

During the past decade and particularly the last three or four years photographic and photogrammetric instruments and techniques have been developed which have materially contributed to the potential of photogrammetry for establishing geodetic control for large-scale mapping. The use of existing passive sunlit satellites for the establishment of a basic control network having a standard error of one part in 100,000, with a station spacing as close as 300 kilometres, has been proven to be attainable and is believed to be both expeditious and economical on a continental basis. (Schmid)[1/]. It now seems altogether reasonable to invert the system and use photogrammetric cameras in satellites or very high altitude aircraft for the second-order densification of the basic 300 kilometre network and at the same time provide adequate geodetic control and photography for large-scale mapping without the need for geodetic work on the ground.

Concurrently with the development of a passive satellite triangulation system, the Coast and Geodetic Survey has investigated the precision of wide-angle metric camera systems to be flown in satellites or very high altitude aircraft. These investigations have included: analysis of changes in the calibrated physical characteristics of photogrammetric cameras operating under arctic and tropical environmental conditions; error propagation studies for both strip and block aerotriangulation with various types of external orientation and scale determining data; experiments with ultra-precise stellar and solar cameras for determining the angular orientation of precisely calibrated airborne mapping cameras; and the investigation of airborne laser ranging systems for precise scale determination. The next few paragraphs express the findings of these investigations and experiments in terms of accuracies believed to be attainable with both presently available and technically feasible cameras when flown in satellites or very high altitude aircraft.

1/ Schmid, Dr. Hellmut H., Accuracy Aspects of a Worldwide Passive Satellite Triangulation System, Photogrammetric Engineering, Vol. 31, No. 1, pp. 104-117.

It appears that the use of a satellite as a camera platform would be most ideal and probably most practicable for the timely densification of geodetic control points in areas where the terrain is difficult and a basic control network has been established with a positional accuracy of 3 metres by photographic observation of passive sunlit satellites. Considering the lowest feasible height for a satellite orbit to be about 200 kilometres, for a duration of a few weeks, the troublesome problems of extended photogrammetric aerial triangulation are avoided because a single photograph could cover the 300 kilometres which corresponds to the spacing of the basic network of geodetic control stations. When treating a few photographs, which in practice must be combined, error propagation can be minimized through the use of orbital constraints such as the consistency of inclination and the smoothness of short arcs. Further geometrical information becomes available if the intervals between photographic exposures are measured with high accuracy (10^{-4} second). (Schmid)[1/]. There is sufficient evidence that geodetic control established by this method will have an accuracy better than 5 metres in three dimensions. This is equivalent to one part in 40,000 of the orbital height which is consistently attainable for short strips or small blocks of aerial photographs made with conventional 100 to 150 millimetre focal length cameras and conventional aircraft.

An alternate method wherein very high altitude aircraft such as the forthcoming supersonic jet transports with operating altitudes of 20 to 25 kilometres are used as platforms for the same type of cameras may warrant consideration. In this case a block of 20 by 20 photographs having 60 per cent endlaps and sidelaps would be required to span the distance of 300 kilometres between basic network control points. Furthermore, the precise geometric orbital constraints which are available with satellite platforms cannot

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1/ Schmid, Dr. Hellmutt H., Satellite Photogrammetry, Jubilee Volume Dedicated to William Schermerhorn on his Seventieth Birthday, W.D. Meinema, Ltd., Delft, 1964.

adequately be replaced with such auxiliary devices as azimuth sensors and doppler exposure interval control. Therefore, for this method of establishing geodetic control adequate for large-scale mapping, the use of a sun imaging lens or camera having an angular precision of 3 or 4 seconds of arc is recommended as an integral part of the mapping camera. In addition, a bore-sighted laser altimeter having an accuracy of one metre is recommended as an integral part of the mapping camera, ideally recording the laser illuminated terrain point on the photograph. It is more difficult to estimate the accuracy of this method, but from experiments and feasibility studies with solar cameras, laser altimeters and system calibration, it seems that error propagation could be controlled to a degree which, together with the larger photographic scale, would enable a three-dimensional accuracy of 2 metres for control established by this method, depending on a reliable geodetic control frame as outlined before.

The development of a new technically feasible photogrammetric camera would improve the accuracy of the previously described satellite-borne camera system by a factor of 1.5 and at the same time increase its ground resolution by a factor of two. The recommended camera would have a wide-angle lens having a focal length of 300 millimetres and a focal plane dimension of 230 to 300 by 450 millimetres. The rectangular format, when oriented with the long dimension in the direction of flight, would give a base to height ratio of 1.0 using alternate photographs when the endlap is 67 per cent. This is most desirable for the execution of three-dimensional triangulation. (Schmid)[1/].

When modern photogrammetric techniques enable heretofore unattainable accuracies, they also dictate stringent requirements on aerial photography both with respect to geometric fidelity and information content. Generally speaking, photograph-measuring instruments and photogrammetric data reduction techniques have now

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1/ Schmid, Dr. Hellmut H., Satellite Photogrammetry, Jubilee Volume Dedicated to William Schermerhorn on his Seventieth Birthday, W.D. Meinema, Ltd., Delft, 1964.

been developed to a higher degree of precision than has the airborne photographic system. (Harris _et.al._, Keller _et.al._)[1/][2/]

The geodetic accuracies expressed in the foregoing discussion are based upon the procurement of aerial photographs which, after mathematical correction for determinable systematic errors, have the properties of a true central perspective projection within the tolerance of a standard error of 3 microns measured in the plane of the photograph. To achieve this goal, special care must be taken in the selection of the camera to ensure that its spatial resolution is of highest quality and that its metrical distortion characteristics have a smooth behaviour and are of such a nature that they can be calibrated, in order to refer the photographic measurements to a central perspective model. The spatial triangulation can then be adequately and reliably expressed by a mathematical model of minimum complexity. The following discussion will call attention to some of the factors considered important in the selection, calibration and use of the aerial photographic system.

There are two basic qualities in which an aerial camera must be unexcelled in order for it to be classified as a geodetic tool. (Schmid)[3/]. The most important quality is sharpness or resolution in the imagery of the resulting photograph. To qualify in this respect, a camera must have a lens which is essentially free from all aberrations including both axial and lateral chromatic aberrations and, at the same time, have a sufficiently large relative aperture to be used with photographic emulsions of medium sensitivity at relatively high shutter speeds. The lens must transmit light of all

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1/ Harris, W.D., Tewinkel, G.C., Whitten, C.A., Analytic Aerotriangulation in the Coast and Geodetic Survey, _Photogrammetric Engineering_, Vol. 28, No. 2, pp. 44-69.

2/ Keller, Morton and Tewinkel, G.C., Analytic Aerotriangulation, Coast and Geodetic Survey Technical Bulletin, Nos. 23, 25, 29 (two more forthcoming).

3/ Schmid, Dr. Hellmut H., Precision Photogrammetry a Tool of Geodesy, _Photogrammetric Engineering_, Vol. 27, No. 5, pp. 779-786.

photographic wavelengths sufficiently well to maintain a balance adequate for colour photography. In addition, the lens combined with its anti-vignetting filter must give a uniform distribution of light over the entire focal plane without significant loss of effective aperture. Finally, it must be rigidly fixed in position and orientation with respect to the focal plane in such a manner that temperature changes will not seriously affect image quality.

The second basic quality required of an aerial camera used for geodetic work is metric fidelity or its ability to produce photographs which are true central perspective projections. This quality is secondary to image sharpness only in so far as departures from a true perspective can be sufficiently compensated through the use of a relatively unsophisticated mathematical model. However, it can be shown that this model can, and indeed must, be more elaborate than those now in general use for photogrammetric mapping.

When considering a sigma of 3 microns as a realistic measure of precision, it is necessary to suppress uncompensated systematic errors or departures from a true central perspective to a fraction thereof. Therefore, in addition to the classic elements of interior orientation, the method of camera calibration must be adequate for defining a distortion model with an over-all accuracy of at least one micron. Present progress leads us to believe that we can attain this accuracy with the same auxiliary equipment and data reduction procedures we use for satellite triangulation. The desired density of one set of star images per square centimetre is obtained by making a series of time-lapse exposures of the celestial sphere on the same photographic plate. By calibrating the camera with the optical filter, which is used for the aerial photography, in position over the lens, any defects the filter may have are also accounted for.

The remaining source of systematic metric error which must be dealt with is the deformation that takes place at the focal plane and in the photographic record. The most obvious and probably the most precise solution to the many problems which arise at this point would be to make each aerial exposure on very thick optically flat glass plates just as we do when we calibrate the camera. However, the problems of logistics, economics and the risk of accidental plate breakage seem to dictate the use of roll film particularly if satellites are to be considered as camera platforms. For this reason, we have been conducting some rather elaborate tests for evaluating the metric behaviour of modern colour and panchromatic aerial films having polyester-type bases.

Inasmuch as film distortion is considered to be the most unpredictable source of error in the entire system, it may be appropriate to summarize our most recent findings. The use of film distortion control grid spacings of either 2 centimetres or 4 centimetres give a standard error of position of 2 microns, suggesting that any closer spacing is unwarranted. When the control grid spacing was increased to 6 centimetres, the standard error increased to 3 microns. When the control grid was eliminated altogether except for 8 points which represent 4 corner and 4 mid-side camera fiducial marks, the standard error of position increased to 4 microns. (Lampton)1/.

The studies also indicate that, while the increase from a random error of 2 microns to an error of 4 microns represents a significant amount of local systematic error, it is still a pseudo random error in so far as error propagation is concerned. Furthermore, in the case of block aerotriangulation using high-altitude aircraft, each geodetic control point established will involve independently perturbed rays from at least 4 and up to 9 different photographs. The averaging effect of these independent rays seems entirely to support those who wish to eliminate the glass camera reseau plate and its degrading effects on image quality. The use of a camera reseau plate may, however, be justified for the case of satellite camera platforms especially if the 230 to 300 by 450 millimetre focal plane format is used.

1/ Lampton, B. Frank, Film Distortion Compensation, Photogrammetric Engineering, Vol. 31, No. 5, pp. 874-883.

The use of colour film is recommended for photography either from satellites or from high-altitude aircraft. The metric and image resolution qualities of modern aerial colour films are now comparable with those of panchromatic films having less than half their sensitivity. By selecting atmospheric conditions suitable for high quality photography, image quality can be improved through the use of colour film with a smaller lens aperture and a faster shutter speed. At the same time the information content of the photograph will be increased many fold through the additional dimension of the colour spectrum. (Swanson)[1/].

It will be necessary to mark all geodetic control points with high-contrast symmetrical target panels prior to the aerial photography in order to be able to measure their photographic image coordinates with a pointing accuracy of 1 or 2 microns. We find a circular or triangular target having a diameter or median length metrically equivalent to 40 microns at the scale of the photograph to be ideal when the target is either white or international signal orange on a green vegetive background. In white sand areas a black target 1.5 times as large must be used to allow for multiple reflection of the light in the photographic emulsion. In addition, a set of identifying panels in a geometric pattern around and in the vicinity of the station marking panel is very advantageous.

The aerial photographic systems defined in this paper are not restricted to satellite and very high-altitude aircraft. The Coast and Geodetic Survey has used cameras of this type with 100 and 150 millimetre focal lengths for several years with colour films. We now use the 8 fiducial mark technique for film distortion compensation and have just completed the more elaborate stellar calibration for two of our cameras. A precise sun imaging camera and a bore-

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1/ Swanson, Capt. L.W., Aerial Photography and Photogrammetry in the Coast and Geodetic Survey, International Archives of Photogrammetry, Vol. 15, Part 2, 29 pages.

sighted laser altimeter are both restricted in their value in our regular work because our coastal areas usually have an abundance of geodetic control.

The principal intent of this paper is to point out the fact that aerial photographic systems are available which, when carefully calibrated and operated under optimized conditions, can produce aerial photography capable of improving photogrammetric mapping accuracy and ground information content by a factor of from 4 to 8 over most systems and techniques now in use.

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