THE RESTITUTION OF METRIC PHOTOGRAPHY TAKEN FROM SPACE

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Abstract

The paper describes the features of space photography which need particular attention when restituting images and gives results from the OEEPE tests of metric camera and large format camera photography. Results show that accuracy approaches that predicted by theory and that the photography can succesfully be used for mapping.

**Introduction**

The interest in the use of photography taken from space for topographic mapping has fluctuated as imagery has become available. The Zeiss Jena MFK-6M multispectral camera has been used for many years but the photography has not been widely used because of lack of availability. The Zeiss (Oberkochen) RMK 30/23 'Metric Camera' has been flown once in 1983 and produced images which are widely available but which, after considerable use, have been judged of limited application. The Itek Large Format Camera (LFC), also flown only once, in 1984, produced better quality images. Now in 1988 photographs from the Soviet KATE 200 and 140 and KFA 1000 cameras are available and once again reviving an interest in photography from space. Photography available is shown in table 1.

Table 1. Photographic data available from space

| CAMERA | PRINCIPAL DISTANCE mm | ALTITUDE km | IMAGE SCALE | FORMAT mm |
|---|---|---|---|---|
| MKF 6M | 100 | 250 | 1:2 500 000 | 58 x 81 |
| RMK 30/23 | 305 | 250 | 1:820 000 | 230 x 230 |
| LFC | 305 | 250 | 1:820 000 | 230 x 460 |
| KATE - 200 | 250 | 250 | 1:1 000 000 | 180 x 180 |
| KATE - 140 | 160 | 250 | 1:1 500 000 | 180 x 180 |
| KFA - 1000 | 1250 | 250 | 1:200 000 | 300 x 300 |

It is possible to orient a pair of photographs taken from space in an analogue plotting instrument, but as Dowman (1984) has shown there are many difficulties to overcome and only a few instruments can handle such images. The analytical stereoplotter is a much more suitable instrument. This judgement is bourne out by the reported practise that most organisations who have worked with space photography have used analytical stereoplotters. Nevertheless there are still problems in using the photography.

This paper will review the data now available and discuss the factors which must be taken into account in using them. These factors include format size, refraction, image quality and ground control. This discussion will be illustrated by practical results from using photography from space from the OEEPE (Organisation Europeene d'Etudes Photogrammetrique Expermentale) tests of Metric Camera and LFC data.

**Special Factors to be considered**

The most important characteristic of photography from space which affects its use, is scale. This clearly limits the accuracy attainable at the ground and the amount of data which can be extracted; it also influences the type of ground control to be used. In order to minimise the effect of high altitude and the speed of the spacecraft, cameras have features such as long principal distances, large formats and image motion compensation. These factors require different instrumentation or techniques for restitution from aerial photography and are now discussed in more detail.

Principal distance and format size.

The effects of increasing principal distance or format size is to increase the scale, thus giving greater accuracy in plan, if only pricipal distance is increased the Base:Height ratio decreases, thus worsening the height accuracy. To remove the latter problem smaller overlaps can be used but the relative orientation then becomes poorly conditioned. In practical terms both large principal distnces and format sizes cannot be accommodated in analogue instruments. Any principal distance can be accepted by an analytical stereo plotter (ASP) and cut down formats can also be accepted providing sufficient fiducial marks are provided.

Image quality

Forward motion compemsation (FMC) clearly improves image quality as demonstrated by the LFC. However the Itek lens has a significant fall off at the edges which makes the use of small overlaps difficult because the worst parts of the images are used.

A problem which was apparent initially, but which may now have been overcome, is that of processing. Centres developed to handle digital data from space had no experience with photographic processing for photogrammetric work and several early reports indicate that products unsuitable for photogrammetric work were produced.

Ground control

Ground control has undoubtedly been one of the most significant problems. Control fixed by field survey for aircraft photography cannot generally be identified on satellite images and the use of co-ordinated points derived from maps has not been satisfactory because of the nature of the maps. A new methodology for obtaining ground control is required which may involve field work using GPS after the images have been obtained. Methods of automatic ground control point detection using map image matching of a large number of points and the development of methods which enable images from different sources to be viewed simultaneously in an ASP may also have some importance.

Refraction

The effect of atmospheric refraction on aerial photography has been investigated in depth by several authors who have showed that the effects of refraction on an image can be corrected given a reasonable model of the atmosphere. Practical experience has generally been limited to altitudes of less than 10km. The effects of refraction across camera windows has also been studied, for example by Meier (1974) and Worton ( 1977), but since camera windows are not in common use and it is difficult to collect data concerning pressure and temperature under flight conditions this aspect is frequently not considered.

The tables available for computing the effect of refraction on photographs do not generally give values for altutudes of above 10km (Schut 1969). Since the pressure is very low above this altitude and little refraction takes place it is assumed that the angular error at the camera is neglibible. This is borne out by the formula of Saastamoinen (1974) for altitudes of over 11km and by use of the formula for stellar parallax given by Bomford (1980). The use of these formulae for altitudes of 250km indicate distortion of about 1$\mu$m.

As explained by Meier (1974) the effect of refraction across a plane parallel glass plate are negligible but if the temperature and pressure on either side of the glass differ then the effect cannot be ignored. Meier showed that displacement in the image $\Delta s$ is given by:

$$\Delta s = (q-1)s + \frac{(q^3 - q)}{2f^2} s^3$$

where $q = n_k/n_a$ ; $n_k$ = refractive index of air at h = 2km;

$n_a$ = refractive index of air at h km;

f = principal distance; s = radial distance on image

At altitudes above 10km, where the effect of atmospheric refraction is decreasing, the total effect of refraction across the window is increasing. If Meier's formula is adopted with the following values:

$$q = n_k/n_a = 1.000214/1; \quad f = 305\text{mm},$$

then for values of s the following table of corrections can be applied:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| s (mm) | 20 | 40 | 60 | 80 | 100 | 120 | 140 |
| $\Delta s$($\mu$m) | 4 | 9 | 13 | 18 | 24 | 30 | 36 |

The effect of this error in a spacelab metric camera image is an error in x parallax in the centre of the model after absolute orientation to points in the corners of the model, an error in height of 50m would result.

Earth Curvature

Correction for earth curvature is not necessary when working with geocentric co-ordinates but is necessary if fitting to co-ordinates on a map projection.

**The OEEPE Metric Camera test**

The Zeiss RMK 30/23 camera, mounted in the European Space Agency Spacelab Module was launched on shuttle mission STS-9 in November 1983. Three photographs from this mission were used in the OEEPE Metric camera test. Images 864,866 and 867 exposed at 1/500 sec on Kodak panchromatic film of a test area in Southern France were used. 11 participating centres used 5 types of instrument including Zeiss, Kern and Matra ASPs, a Wild stereocomparator and Zeiss Planimat D2.

Participants were required to set up two models 864/866 (60% overlap) and 864/867 (20% overlap) to ground control and then identify and record co-ordinates of check points. Besides ground control co-ordinates in Lambert and Geocentric co-ordinates and location data from a catologue prepared by IGN (France) the shuttle ephemeris data distributed by NASA was provided.

Tables 2 to 5 indicate the methods used and the results obtained in setting up the models from all the centres for the four different model/co-ordinate system possibilities. A number of conclusions can be immediately drawn from these tables:

The results within each group are generally consistent.

The accuracy of the height co-ordinate improves with 20% overlap.

The results when using Lambert co-ordinates are better than those when using geocentric co-ordinates.

Table 2. Results from absolute orientation for model with 60% overlap using geocentric (or local rectangular LV) co-ordinates.

| Centre | Method | | Root mean square error of Residuals (m) | | | | |
|---|---|---|---|---|---|---|---|
| | | No Pts | dx | dy | dz | V | System |
| 11 | Plan height iteration of block PAT-M 43 | 14 | 31 | 30 | 43 | 61 | LV |
| 21 | PAT-M 43 | 19 | 27 | 20 | | | LV |
| | | 21 | | | 39 | 51 | LV |
| 41 | ? | 18 | 31 | 34 | 25 | 52 | |
| 51 | Plan height iteration. Final orientation in another computer. | 22 | 29 | 32 | 43 | 61 | LV |
| 72 | Analogue instrument | 17 | 21 | 21 | 23 | 34 | LV |
| 74 | Standard Zeiss software | 19 | 20 | 22 | 29 | 41 | LV |
| 75 | Standard Kern software | 13 | | 13 | 42 | | ** |
| 101 | IGN software | 22 | 22 | 21 | 15 | 34 | |
| 111 | Standard Kern Software. | 21 | 22 | 20 | 24 | 38 | LV |
| 112 | Standard Kern Software | 17 | 22 | 20 | 30 | 42 | |

Table 3. Results from absolute orientation for model with 60% overlap using Lambert co-ordinates.

| Centre | Method | Root mean square error of Residuals (m) | | | | |
|---|---|---|---|---|---|---|
| | | No Pts | dx | dy | dz | V |
| 41 | Bundle method | 20 | 27 | 18 | 28 | 61 |
| 73 | Standard Zeiss software | 18 | 15 | 16 | 21 | 30 |
| 74 | Standard Zeiss software | 19 | 21 | 21 | 22 | 37 |
| 75 | Standard Kern software | 13 | | 11 | 25 | 27 |
| 111 | Standard Kern Software. | 20 | 25 | 21 | 28 | 43 |

Table 4. Results from absolute orientation for model with 20% overlap using geocentric (or local rectangular LV) co-ordinates.

| Centre | Method | Root mean square error of Residuals (m) | | | | | |
|---|---|---|---|---|---|---|---|
| | | No Pts | dx | dy | dz | V | System |
| 11 | Plan height iteration of block PAT-M 43 | 9 | 16 | 28 | 29 | 43 | LV |
| 21 | PAT-M 43 | 13 | 18 | 18 | 19 | 31 | LV |
| 41 | ? | 11 | 22 | 25 | 20 | 40 | |
| 51 | Plan height iteration. Final orientation in another computer. | 14 | 29 | 19 | 34 | 34 | LV |
| 72 | Analogue instrument | 11 | 17 | 16 | 17 | 26 | LV |
| 74 | Standard Zeiss software | 12 | 20 | 20 | 19 | 34 | LV |
| 101 | IGN software | 13 | 11 | 11 | 19 | 25 | |
| 111 | Standard Kern Software. | 14 | 17 | 16 | 27 | 36 | LV |
| 112 | Standard Kern Software | 11 | 20 | 22 | 30 | 42 | |

Table 5. Results from absolute orientation for model with 20% overlap using Lambert co-ordinates.

| Centre | Method | No Pts | Root mean square error of Residuals (m) dx | dy | dz | V |
|---|---|---|---|---|---|---|
| 41 | Bundle method | 12 | 19 | 22 | 13 | 32 |
| 73 | Standard Zeiss software | 12 | 8 | 11 | 14 | 20 |
| 74 | Standard Zeiss software | 12 | 16 | 22 | 11 | 29 |
| 111 | Standard Kern Software. | 14 | 22 | 20 | 29 | 42 |

These results will now be examined in more detail considering the parameters listed above.

The variations within the groups shown in tables 2 to 5 are greater than variations within groups arranged according to different parameters. Thus no useful comments can be made on the type of instrument used or the method of orientation.

Different co-ordinate systems

Fewer centres used Lambert co-ordinates and hence the conclusions to be drawn are more limited. Centres 41, 74 and 111 used both sets and in two of the cases for the 60% overlap the results were better with Lambert, in the third case the result was worse, in the case of the 20% overlap the results were improved in all three cases. One centre used only Lambert co-ordinates and results were better than the average for those centres using geocentric. The improvment between 60% and 20% overlap was also more marked.

These results lead to a tentative conclusion that better results can be obtained using projection co-ordinates with an earth curvature compensation that with using geocentric co-ordinates.

Different overlap

The Base:Height ratio for the model with 60% overlap is 0.3 whilst that for the model with 20% overlap is 0.6, thus in theory there is a ratio between the height accuracy of the two models of 2. A comparison of results shown in tables 2 and 4 shows a general improvement in height. The factor of improvement varies between 1.2 and 1.9 but there seems to be no consistemcy within the results. The results in plan also show an improvement in all cases, this can be explained by improved stereoscopic pointing.

Distribution of errors

The most surprising result from the absolute orientation was the systematic error present in the heights. Plots of height residuals from all centres using geocentric and Lambert co-ordinates show a dome shaped pattern and is of a similar magnitude in all cases. The pattern is not one associated with errors in relative orientation or due to lens distortion.

The error is consistent with refraction due to pressure change across the camera window as discussed abpove. In order to test this possibility further tests were carried out at the pilot centre.

The corrections set out in above were added to the lens distortion correction in the camera file of the DSR1 and the model was set up again to ground control in the geocentric system and the Lambert system. The new residuals in height, together with the original residuals are shown in table 6.

The first point to note about these results is the variation in residuals between sets, there is clearly a significant standard deviation of the observations but there is also a trend showing the points in the centre of the model to have lower heights in the corrected sets of co-ordinates. This test is by no means conclusive and more work needs to be carried out into this effect.

Table 6. Residuals from absolute orientation after application of correction for refraction (µm).

| Point | Original geocentric | Original Lambert | Corrected Geocentric | Corrected Lambert |
|---|---|---|---|---|
| 7022 | 32 | 40 | 11 | 28 |
| 2015 | 16 | 29 | 51 | 36 |
| 1003 | 13 | 12 | 29 | 37 |
| 3010 | -23 | -111 | -85 | -42 |
| 4001 | -69 | -32 | -31 | -45 |
| 5004 | -8 | -93 | -120 | -98 |
| 8004 | 31 | 12 | 10 | 9 |
| 1016 | -78 | -17 | -24 | -13 |
| 1017 | 7 | 35 | 36 | 34 |
| 2012 | 7 | 20 | -2 | -14 |
| 2016 | -14 | -38 | -13 | -17 |
| 3012 | -19 | -36 | -40 | 25 |
| 3017 | 36 | 45 | 2 | 93 |
| 4016 | -41 | -50 | -64 | -66 |
| 5014 | -97 | -64 | -44 | -55 |
| 7018 | -42 | -7 | -25 | -14 |
| 7024 | -9 | -6 | -17 | 2 |
| 8024 | 8 | 23 | 25 | 13 |
| 8025 | 18 | -31 | 1 | -20 |
| 9014 | -1 | -19 | 28 | 5 |
| 9017 | -9 | -14 | -10 | -8 |
| 9026 | 0 | 35 | 15 | 38 |
| SUM | -242 | -267 | -267 | -72 |
| RMSE | 36 | 43 | 42 | 41 |

Analogue instruments

Centre number 72 used a Zeiss Planimat instrument for the test and centre number 75 used a Kern DSR11 in order to simulate an analogue instrument.

Centre 72 carried out tests with geocentric co-ordinates, rotated to the local vertical, without applying any corrections to the photograph or model. The results are equal to the best from any test centre. Some results with the Zeiss Jena Topocart were described at the Metric Camera Workshop (Bahr, 1985), but the work for the OEEPE test was carried out on a Kern

DSR11 and tests were made on full and partial models with and without earth curvature correction. In all cases the use of an earth curvature correction improves the results in height. The use of earth curvature improves the results even when geocentric co-ordinates are used. The use of part models however does not improve the result.

**Results from the OEEPE LFC test**

The OEEPE test of LFC data was designed to test the use of photography from space for mapping in dedveloping areas. A test site in Sudan was chosen, recent mapping and control were available from the Ordnance Survey (UK) by permission of the Sudanese government. The overlapping portion of images 1864 and 1865, exposed on Kodak SO-131 Colour infra red film were used. The quality of the first set of diapositives received fom Eros Data Centre (EDC) was quite unsuitable for photogrammertric work, EDC replaced these but the quality was still not entirely satisfactory.

Co-ordinates of 10 points were provided as control and descriptions of a further 22 points were provided of check points. The point descriptions were in the form of point descriptions and reduced aerial photographs of the points. The control came from ground survey and aerial triangulation the majority of points were small features such as isolated bushes which proved difficult to identify on the false colour images. The position of the points was also marked onto an overlay. Participants were also provided with camera calibration data and the shuttle ephemeris data provided by NASA to use as they thought fit. Participants were asked to set up a model and produce a plot at 1:100 000 scale. A Sudan Survey Department 1:100 000 map of an adjacent area was provided

11 centres participated in the test, all used analytical stereo plotters which included Kern DSR, Matra, Zeiss Planicomp, Wild AC1 and BC2. All participants reported difficulties with using the control points, 2 centres decided not to continue with the test because of this problem, only the Ordnance Survey used a Wild PUG for transfer of points from the aerial photographs, all other centres used visual inspection methods, although 2 centres carried out the transfer onto enlarged LFC images.

Although provided with the calibration data for the reseau in the LFC participants all carried out inner orientation to the fiducial marks only, results were gererally not very good, rmse being generally greater than 10μm even after an affine transformation. All but one centre applied correction for radial lens distortion. Relative orienation provided no difficulties and in all but one case produced rmse y parallaxes of less than 7μm.

The results of absolute orientation varied significantly. Only one participant used geocentric co-ordinates . Of the 10 control points provided only 7 or 8 could be identified in most cases, the average rmse was 33m in plan and 11m in height. Results from the absolute orientation and from measurement to check points are shown in table 7.

Table 7. Results from absolute orientation of large format camera model

| CENTRE | CO-ORD SYSTEM | NO PLAN | NO HT | CONTROL RMSE (m) X | CONTROL RMSE (m) Y | CONTROL RMSE (m) Z | CHECK PTS NO | CHECK PTS RMSE (m) X | CHECK PTS RMSE (m) Y | CHECK PTS RMSE (m) Z |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GEO | 7 | 10 | 15 | 23 | 25 | 16 | 113 | 170 | 12 |
| 2 | UTM | 8 | 10 | 25 | 46 | 7 | 21 | 104 | 138 | 20 |
| 4 | UTM | 9 | 9 | 7 | 15 | 15 | 21 | 154 | 150 | 31 |
| 5 | UTM | 6 | 6 | 6 | 9 | 13 | 16 | 91 | 119 | 23 |
| 7 | UTM | 9 | 9 | 274 | 240 | 57 | | | | |
| 8 | UTM | 5 | 5 | 60 | 137 | 57 | 3 | 134 | 151 | 756 |
| 9 | UTM | 7 | 8 | 35 | 67 | 24 | | | | |
| 10 | UTM | 10 | 10 | 8 | 8 | 7 | 22 | 584 | 690 | 47 |
| 11 | UTM | 8 | 8 | 23 | 25 | 12 | 17 | 81 | 161 | 49 |

The results from measuring the check points show a five fold deterioration in accuracy. It is clear from the comments made that this is due to difficulties in identification of points. There was also a significant component of systematic error on the results.

Plotting was also carried out in the LFC test. 5 centres completed a plot with detail and contours. Many of the major features of communications and settlement were identified although it is clear that considerable field completion would be necessary for 1:100 000 mapping.

**Conclusions**

It has been shown by the OEEPE tets that analytical stereoplotters can be used to set up and plotted from space photography with little or no difficulty. The problems arise in obtaining suitable control which can be identified on the image with accuracy comensurate with the accuracy of the control required for absolute orientation. A suitable model for correcting refraction must also be developed further and tested although problems with this have not been identified on all tests carried out on MC and LFC photography. The theoretical increase in height accuracy expected with a better base:height ratio is not fully realised, probably due to fall off in image quality towards the edge of the image. An improved plan accuracy with the better base:height ratio was not expected but was clearly present.

Other tests reported at the Metric Camera Workshop (ESA, 1985) and in various publications on LFC photography (for example Derenyi and Newton, 1986, Togliatti and Moriondo, 1986) indicate similar results. The tests of plotting from MC and LFC have not been very rigorous but the indication is that mapping can be carried out at 1:100 000 scale but that a considerable amount of field completion is still required.

The Soviet KFA-1000 camera producing photographs at a scale of 1:200 000 provides imagery of a resolution not previously available to civilian mapping organisations. Tests of the type described on that photography should be quickly and efficiently carried out and results may already be available at the Congress. They are expected to show greater plan accuracy and content than with previous imagery although the 300mm format may provide some problems in inner orientation.

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