CARTOGRAPHIC ACCURACY AND INFORMATION CONTENT OF SPACE IMAGERY FOR DIGITAL MAP COMPILATION AND MAP REVISION

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Abstract

This paper first evaluates the existing space imagery both in photographic and digital form which is suitable for topographic mapping at medium and small scales. This includes data taken with the ZEISS metric camera, ITEK large format camera, Landsat Thematic Mapper (TM) and Multi-Spectral Scanner (MSS).

Photogrammetric techniques have been used in a KERN DSR1 analytical stereoplotter and in a digital mono comparator plotter, the latter developed by this author, in order to evaluate how accurately ground co-ordinates can be obtained from the imagery. New methods have been employed to compute a good first approximation to the exterior orientation elements, based on ground control points.

A study is presented on the corrections to be applied for the effect of atmospheric refraction, earth curvature, tilt and relief displacement. Computer programs have been written to convert co-ordinates to and from several different systems.

Digital Terrain Models (DTMs) derived from aerial photographs were used with a digitised space photograph allowing correction for relief displacement. Height interpolation routines have been implemented and sorting of data programs written to access the data quickly as well as to perform a data compression of the DTM data.

Techniques have been developed in order to generate digital image-maps, using DTMs and digital space imagery. A digital database has been derived by digitising topographic maps in vector form; this data has been overlaid with the imagery through graphics planes, allowing direct comparison between the existing map and the newly compiled maps from the imagery.

Conventional and newly developed image processing techniques have been applied to enhance the imagery for visual and semi-automatic extraction of map data. New techniques of extracting such information and merging it with digitised map data are described.

Evaluation has also been done on the cultural information present in the imagery, which could be vector digitised and utilised for topographic mapping and map revision. Final products in form of line graph and image maps are presented.

1. Introduction

The great worldwide demand for maps, mainly in the developing countries, imposes a need for the acquisition of imagery from space, which would cover large areas at a reasonably high speed, with reduction in the density of geodetic control.

Many systems have been employed and proposed in the last two decades. Some of them have indeed provided a source of data for mapping at small scales, but no space imagery available for civilian purposes has yet proved good enough for mapping at medium scales.

Perhaps none of the existing systems can offer the final solution to the problem of data acquisition, but the combination of various systems could lead to an acceptable coverage of the world's demand for maps.

The end of this decade is seeing new technological developments in this field and most certainly the next decade will see better, faster and perhaps cheaper methods of acquiring data and producing and/or revising topographic maps at the scales of 1:50 000 and 1:100 000 so much in need by many countries.

This paper contains a compilation of the methodology employed and results achieved by this author and presented in her Ph.D thesis (Meneguette, 1987). The study aims at employing some of the existing image forming systems as a source of data for mapping as well as at developing new techniques for digital map compilation and map revision at medium and small scales.

Special attention is paid to geometric accuracy obtained by the use of photographic and scanning systems, but the emphasis of this work is on the map information content of space imagery and the cartographic accuracy which can be obtained from line graph and image maps.

2. Methodology

2.1 Acquisition and computation of terrain data

The use of ground control is probably the surest and most accurate way of orienting images to the ground. In this work coordinates of selected control points have been read off 1:25 000 and 1:50 000 scale maps.

A suite of programs developed by this author allowed the conversion of such coordinates into any desired coordinate system. Additional control in some test areas was also supplied by mapping agencies (IGN-France, Ordnance Survey-UK).

In order to keep a digital record of the ground control points used in this study, files were created, containing the points reference number, followed by the coordinates given in any chosen system.

In addition to ground control in form of control points, Digital Terrain Models (DTMs) were generated from aerial photographs and existing topographic maps were vector digitised.

The resulting database contains most of the information displayed in the map, namely, main roads, minor roads, railways, rivers, lakes, coast-line, streets, canals, footpaths, car tracks, reservoirs, salt pans, etc. All these features have been digitised separately, forming files with points, strings, links and polygons, containing specific information.

With respect to the digital terrain models, the method adopted in this study for acquisition of data has been the generation of regular grids, using newly developed software in a Kern DSR1 photogrammetric analytical stereoplotter.

This DTM data has been processed by employing subroutines written by this author, in order to carry out data compression by discarding all information that can be retrieved at a later stage. Height interpolation routines have been implemented and sorting of data programs written to access the data quickly.

2.2 Analytical restitution of imagery

The extraction of geometric information from the imagery requires the knowledge of the mathematical relationship between the image and object space. The sensor used to form the image is very important as there are different approaches to the restitution of imagery depending on the image forming system.

In this work space photographs as well as scanner imagery have been employed, therefore a distinction has to be made between the two systems.

2.2.1 Restitution of space photography

Restitution of photographs was done by adopting the collinearity equations and was performed by setting up stereomodels entirely on the analytical stereoplotter Kern DSR1 (Meneguette, 1985).

The basic model formation process is identical whether images are taken from space with metric cameras, or from an aircraft, as in conventional photogrammetry. However, because of the camera altitude and scale of the photographs special consideration has to be paid to the methods used to create the model and determine the elements of exterior orientation.

The first step, as with any photography, is to remove the effect of lens distortion and film deformation. No correction has been applied to image coordinates for the effect of camera window because its influence on the quality of the photographs was shown to be negligible (Schroeder, 1982).

The effect of atmospheric refraction has been carefully studied by applying techniques proposed by several authors (Schut, 1969; Saastamoinen, 1972 and 1974; Bomford, 1984; Forrest, 1974).

Tests have been carried out in order to evaluate the effect of atmospheric refraction on the coordinates, and to compute the compensation to be applied. The aplication of corrections to either image or ground coordinates has been shown to be necessary.

The effect of earth curvature was shown to be relevant and thus care has been taken in order to solve for the problem. This has been done by either applying a displacement to image coordinates, or more effectively, by employing the geocentric coordinates system.

The contribution of earth curvature to the refraction is said to be very small (Schut, 1969) and therefore has been ommitted. Also, high altitude photography of an area manifests less relief displacement than low altitude photography.

2.2.2 Restitution of scanner imagery

In this study, scanner imagery has been evaluated using the digital monocomparator plotter, developed by this author (Meneguette, 1987), which comprises a suite of computer programs written in Fortran 77 using an I^2S model 75 image processor linked to a VAX 11/750.

Single images, either digital satellite imagery or digitised photographs, digital terrain models and vector digitised databases are the inputs to the system, while new compiled or revised topographic and thematic maps are output.

Welch et al (1985) conclude that polynomials of the first degree and as few as four ground control points were adequate to fit images to UTM map coordinate system to subpixel accuracies.

This method has therefore been adopted in the present work when dealing with Landsat imagery. However, a space resection had to be carried out when using digitised space photography. Therefore, the digital monocomparator plotter allows the use of imagery obtained with the use of different sensors, by calling specific subroutines which carry out the actual analytical restitution of the imagery.

2.3 Map compilation and map revision

All stages of orientation of space photographs were carried out on the analytical stereoplotter Kern DSR1, namely, the camera calibration, inner, relative and absolute orientations.

These tasks were followed by on-line compilation and/or off-line plotting of maps on the Kern GP1 graphics peripheral, using the Kern Maps 200 software package.

In the case of digital satellite imagery, the digital monocomparator plotter was employed since it allows the analytical restitution of imagery to take place, as well as the generation and display of digital files containing information extracted from the imagery or existing map.

Conventional and newly developed image processing techniques have been applied to enhance the imagery for visual and semi-automatic extraction of map data. A new method was also developed by this author based upon the well-known vegetation indices, which caused a vegetation suppression and enhancement of non-vegetated areas.

Techniques were developed during this study in order to generate digital image-maps, using DTMs and digital space imagery. The I^2S image processor system 575 already has some built-in software for geometric correction of imagery. However, one of the disadvantages of employing such warping function is that all points are considered as control, and, depending upon the number of points used, the order of the polynomial is determined. This leads to the problem of lack of test points, and therefore, of information about the quality of the warp operation.

Also, the resulting image pixel positions do not have a special relationship with any projection system. These problems have been overcome by writing new software that allows the selection of both control and test points; in addition to that, the program computes the input pixel addresses corresponding to specific points of a grid system. Therefore, the output is an image map whose pixel positions keep as close a relationship with the base map as the corresponding areas on the map themselves.

When a DTM is available, it is also possible to generate orthoimages from both digital satellite imagery and digitised photography. Although the mathematical modelling is different in each of the programs due to the distinct geometry of the sensors involved, the general facilities are very similar.

Techniques of extracting cultural information and merging it with digitised map data were employed. Digital image maps can be displayed simultaneously on the screen by employing the split screen function of the I^2S or they can be registered for direct visual comparison. Another choice is the superposition of imagery, either by showing the satellite image as a 3-band combination and the map image through the graphics planes, or else, two bands of the satellite image can be selected and the third can be replaced by the map image in raster form.

In this work, the vector digitised topographic maps were also overlaid with the imagery through graphics planes, allowing direct comparison between the existing map and the newly compiled maps from the imagery.

Quantitative tests have been performed on maps at various scales, by selecting some samples of cultural features normally found at all scales and comparing the extent of these on the newly generated maps with the amount found on the existing maps. Comparisons have been carried out using maps both in digital and graphical form.

In the case of comparison of graphical output, the method adopted has been to overlay the newly derived maps, plotted on transparent material onto the existing maps. The inverse procedure has also been adopted as to allow double check to take place.

Lengths of roads have been read off maps directly, when available, otherwise a map measuring device has been utilised and readings were transformed into the particular scale of the maps being measured. Linear features have been subdivided as correctly and incorrectly classified. The difference between the length of the correctly classified features, which were measured on newly compiled and existing maps, has been considered the amount of missing information. Results were presented as percentage when comparing lengths of features on existing maps and those plotted from space imagery.

Digital maps have also been compared by several methods. One of them involves the display of cartographic images through the graphics planes, which allows different colour combinations. By employing this method, in which each type of feature is considered at a time, both maps, namely the vector digitised map from the existing map and the newly digitised map from the imagery, can be seen simultaneously.

Since different colours are assigned to each of the data being displayed, it is very easy to know which string belongs to which data set. When corresponding lines present in both maps are displayed at the same location, there is a change of colour, which does not necessarily mean a match. Care had to be taken when selecting the samples, so that surrounding lines could not interfere with the ones being considered.

Therefore, in order to compare results more directly and adopt a standard method, the digital maps generated from satellite imagery were plotted in the same way as the ones derived from space photography and the previously mentioned procedures were employed in order to find out the completeness results.

3. Test data

High resolution space photography has been acquired by two separate missions of the American Space Shuttle, the first being during the Spacelab experiment in December 1983 (metric camera); while the second of them was carried out in October 1984 (large format camera).

In this evaluation, panchromatic metric camera photographs of two test areas have been used. Photographs 717 and 718 (strip 24) taken at 07:26 GMT on 5 December, 1983 cover an area of the coast of Libya and the Mediterranean Sea.

This model is partly cloud covered which causes some parts of the coastal area to be dark; the upper part of the model could not be seen at all. In the lower part of the model, it has been noticed that near the edges of the photographs, mainly in photograph 718, there was very poor image quality.

Photographs 864, 866 and 867 (strip 25) taken at 09:00 GMT on 5 December, 1983 cover the second test area, which is located in Southeast France to the north of Marseille and the Rhône Delta. This area has a variable relief and shows the Mediterranean Sea and part of the Alps. Overlaps of 60% and 80% have been evaluated.

The quality of photographs used in this analysis was not so high as was expected, probably due to the conditions under which they were acquired.

The main problem noticed in the French model was the lack of one fiducial mark (photograph 866) which was probably due to the spool problem that occurred during the taking of the photographs in space and the unflatness of the film. There was also unsharpness in some parts of the photographs and the image quality seems to vary from photograph to photograph.

The second source of data in photographic form used in this study was the Large Format Camera (LFC). Black and white copies of photographs originally taken with colour infrared (CIR) film have been supplied for this evaluation. The photographs used here were number 1863, 1864 and 1865 of day 285 taken at 10:59 GMT, at a flying height of 250 km. The ground area covered by the photographs is in Sudan, Africa.

There seems to have been some loss of image quality in the diapositives used in this evaluation, due to the fact that they were fourth generation copies from CIR third generation copies. The fiducial marks, especially in diapositive 1864 have very bad image quality which lowers the pointing accuracy during inner orientation.

In addition to space photography, aerial photography has also been used in this study, in order to allow the acquisition of Digital Terrain Models (DTM) and densification of ground control over the European test site, also covered by the metric camera experiment.

In this evaluation only the photographs number 3 and 4 have been used. The photographs at a nominal scale of 1:60 000 were acquired by a 152 mm focal length camera from an altitude of 10 km, and have been suppliued by the French Geographical Institute (IGN-F).

Space imagery in digital form has also been utilised in this study, mainly supplied by Landsat, but also digitised space photography was evaluated.

Landsat Thematic Mapper (TM) scanner imagery has been the main source of digital data employed, although Multispectral Scanner (MSS) imagery has also been evaluated.

A subscene from Landsat-5 TM image number 196.30 of 14 July, 1984 over Southeast France was used in order to determine the geometric accuracy in plan that can be attained from the digital imagery, as well as the cultural information for topographic map compilation and revision.

This subimage has also been employed for the application of digital image processing techniques, which enhance the imagery for visual detection and interpretation. The enhanced subimage has then been used in the development and testing of new techniques of extracting cultural information from the imagery and merging it with the digitised map data.

Other subimages have also been utilised in order to carry out tests with the digital monocomparator plotter developed by this author. These 512 x 512 pixels subimages covered areas in Tanzania, Italy, Tunisia and Brazil, and were acquired by Landsat-2 and -5 MSS and TM sensors.

4. Analysis of results

When a comparison is made between the accuracy results obtained for space photography (both metric camera and large format camera) with those for scanner imagery, it is possible to conclude that similar figures can be achieved.

The analytical restitution of space photography has been performed employing the methods already described in Section 2.2.1, which consisted mainly of carrying out the inner and exterior orientation.

Despite the image quality problem, and the lack of one fiducial mark in metric camera photograph 866, inner orientation has been achieved with largest residual values not greater than 23 μm. The results of relative orientation were also acceptable, with largest parallax value of 10 μm for the metric camera and 18 μm for the large format camera.

In general, absolute orientation has been carried out without serious difficulties, since a new method of computing the initial approximation has been employed.

Corrections have been applied, when necessary, to coordinates due to the effect of earth curvature and atmospheric refraction, showing that the effect of such sources of error is not negligible.

Tests were carried out in order to evaluate the effect of atmospheric refraction on the image coordinates, and to compute the compensation to be applied by employing the existing methods. Results obtained are very similar despite the methods used be different.

The value of the correction at image scale is larger for Landsat than it is for metric camera and large format camera because a longer focal length is used on the Landsat TM sensor, which together with a smaller geometric nadir angle leads to greater figures. Thus, at an angle of 45°, the correction for both space photographs would be 5.7 μm at image scale or 4.7 metres at ground scale, while for Landsat TM the correction would reach 16.1 μm and 4.7 metres respectively.

However, the effect of earth curvature on the image coordinates is much greater on a space photograph than on a Landsat TM image. Actualy, the effect on TM images, in pixel size terms, is only noticeable after distance 220 mm, when it becomes greater than 30 metres (ie, 37.2 metres at ground scale or 128.7 μm at image scale), reaching less than 3 pixels at the edge of the scan line (which is 319.8 mm away from the nadir point, taken as the origin).

For metric camera photographs, at the radial distance of 100 mm, the earth curvature correction reaches 173 metres (211 μm, at image scale), while at the radial distance of 220 mm on a large format camera photograph, the correction would be over 1.8 km (2244 μm, at image scale).

Relief displacement is another source of error to be dealt with. Results at image scale are very similar whenever space photography or TM scanner imagery is employed. However, for a point at the edge of the frame with a height of 1000 metres, the displacement on a TM image corresponds to about 4 pixels (131 metres), while for a photograph, a larger figure of 377 metres is obtained.

The error due to map projection is much greater on a large format camera aft and forward section than it is on a metric camera photograph and large format central portion. While for the latter the error reaches 118 μm at image scale or 96 metres at ground scale (for a point 115 mm away from the origin), in the former case, error of 330 μm or 270 metres respectively is found for a point at a radial distance of 230 mm. For the TM image, the error is very similar to that obtained for the metric camera and equals 309 μm at image scale or 89 metres at ground scale.

Accuracy of 20 to 30 metres in plan and 40 metres in height has been achieved when correction for effects of earth curvature and atmospheric refraction were not applied.

Improved results were obtained afterwards, with such corrections being applied, and final figures for absolute orientation show that ground coordinates can be obtained from the photography with accuracies of about 6 to 20 metres in plan and 5 to 10 metres in height at scales of approximately 1:800 000.

The digital monocomparator plotter has been utilised during the analytical restitution of digital satellite imagery and digitised spaced photography, as mentioned in Section 2.2.2.

Results are encouraging, since by applying an affine transformation to at least four control points, Landsat imagery has been restituted with accuracies in plan of about ± 1/3 pixel to ± 1 pixel for both the TM and MSS sensors. These values correspond to about 10 to 30 metres for the TM, and 26 to 80 metres for the MSS.

In the case of digitised space photography, inner orientation has been performed, resulting in an accuracy figure of 3 μm, while space resection results show that ground coordinates can be measured on the imagery with an accuracy of 24 metres in plan and 9 metres in height.

Maps in digital and graphic form have been generated for areas in France, Libya and Brazil. Unfortunately, due to non-availability of maps covering the area in Sudan, photographed by the large format camera, at least at time of setting up the models on the Kern DSR1, no plotting has been carried out from these photographs.

Maps generated for the French area have been derived from metric camera photographs, as well as from Landsat TM images, and were plotted at the scales of 1:100 000 and 1:200 000. France has a wide selection of maps at different scales which could be used for comparison with the newly compiled maps.

The Libyan area covered by metric camera photographs has been plotted at 1:50 000 scale in order to allow direct comparison with the existing map. Another area in Libya was plotted at 1:100 000 scale and comparisons made between the newly compiled map and the existing maps dated from 1962 and 1979.

The test area in Brazil is located in one of the best served regions of the country in terms of maps, hence, a series of maps was available. New maps at 1:50 000 and 1:100 000 were plotted from TM imagery so as to allow a comparison with the existing maps at such scales which were compiled in 1971, 1979 and 1984.

In order to find out the accuracy of the newly compiled maps, sets of coordinates were compared and the root mean square error (rmse) of the residuals have been computed. Results indicate that ground control plays a very important role in the final accuracy values.

According to the map accuracy standards, the results obtained for control points in most cases fall within the accuracy required for maps at 1:100 000 scale, when the metric camera is considered. For plots from Landsat TM images, standards are fullfilled for scales ranging from 1:50 000 to 1:100 000.

For test points, however, accuracy standards for scales smaller than 1:100 000, and in some cases 1:200 000, are reached when plots from metric camera are considered. For plots generated from Landsat TM, standards of 1:130 000 to about 1:300 000 scale are achieved.

Digital image maps have also been considered; results of applying the warp function on the image processor have shown that average errors between 0.4 pixel and 0.3 pixel, which correspond to about 12 metres and 9 metres respectively, can be obtained from TM imagery. This would be enough to reach accuracy standards of maps at 1:25 000 and 1:50 000 scales.

In the case of digitised metric camera photograph, however, results of 0.5 pixel or about 10 metres have been obtained, because the image had been subsampled previous to the warp. Nevertheless, accuracy standards for mapping at 1:50 000 scale should be fullfilled.

Although the average errors could indicate a rather optimistic allowable map scale for topographic mapping application, this would be misleading, since only small areas of a whole image were considered and a few points were utilised.

More important than the geometric accuracy that can be obtained from such maps, is the actual cultural information content present in them. For the French area, completeness results of 1:100 000 scale plots from space imagery, as compared to existing maps at 1:100 000 (IGN-F) and

1:200 000 scale (Michelin), have indicated that reliable mapping could not be carried out at 1:100 000 scale. This is due to the low percentage of features present in the newly plotted maps.

If results obtained are considered, not even mapping at 1:250 000 scale would be done adequately. For the TM improved results over the metric camera were obtained. If restrictions were made concerning the feature type to be considered in the evaluation, mapping could be achieved from the TM imagery at both 1:100 000 and 1:200 000 scale, while for metric camera plots, still 1:250 000 scale would be more appropriate.

Similar conclusions are achieved concerning the Libyan area, for which metric camera plots were prepared at 1:50 000 and 1:100 000 scales. Mapping at medium scales should therefore not be carried out from this source of data, since the amount of missing information would be over the accepted limits, even for developing countries. Space photography could be used when establishing priority areas for map revision, but not for reliable topographic mapping.

For the Brazilian test area, which has been covered merely by Thematic Mapper imagery, the quantitative test has shown that, despite the excelent geometric accuracy results previously obtained, neither mapping at 1:50 000 nor at 1:100 000 scale should be carried out. The partial identification, if not total absence, of important cultural features for topographic mapping and map revision may make this data set unsuitable for such applications.

5. Conclusions

In general, it can be said that, despite good analytical results obtained after absolute orientation, the results achieved in this study for the information content of imagery and completeness of maps are far from ideal and may seem discouraging.

However, it has to be taken into account that, considering the wide choice of technical possibilities that exists nowadays, further tests to be carried out in near future may provide a different answer.

This work has presented conventional and new methodologies to be considered, and possibly adopted, by other researchers when evaluating similar sets of data. New sources of imagery are becoming available and more research is required in the field of cartographic accuracy and information content, in order to establish methods and standards.

More important than that, is the actual application of space imagery to topographic mapping and map revision, mainly in those areas of the planet so much in need of updated base maps.

References

Bomford G., 1984. Geodesy. Clarendon Press, Oxford. 4th edition. 855 pages.

Forrest R. and Derouchie W., 1974. Refraction Compensation. Photogrammetric Engineering and Remote Sensing, 40():577-582.

Meneguette A., 1985. Evaluation of metric camera photographs for mapping and co-ordinate determination. Photogrammetric Record, 11(66):699-709.

Meneguette A., 1987. Cartographic accuracy and information content of space imagery for digital map compilation and map revision. Ph.D thesis, University of London, 464 pages.

Saastamoinen J., 1972. Refraction. Photogrammetric Engineering. 38(8): 700-810.

Saastamoinen J., 1974. Local variation of photogrammetric refraction. Photogrammetric Engineering, 40(3): 295-301.

Schut G., 1969. Photogrammetric refraction. Photogrammetric Engineering, 35(1):79-86.

Welch R., Jordan T., Ehlers M., 1985. Comparative evaluations of the geodetic accuracy and cartographic potential of Landsat-4 and Landsat-5 Thematic Mapper image data. Photogrammetric Engineering and Remote Sensing, 51(9):1249-1262.