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AN AUTOMIZED SMALL SCALE MAPPING PROJECT

a preliminary report

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Abstract.

The Geodetic Institute of Denmark has started a mapping project in the northern parts of Greenland. The mapping is to be based on a production of numerically controlled orthophotos with superimposed contourlines.

Approximately 110 sheets of orthophotomaps on the scale ratio of 1:100,000 covering all 300,000 km^2 of the ice-free part of Northern Greenland are to be produced.

A special photo mission with super wide-angle camera and an image scale of 1:150,000 was carried out in 1978. The individual models are scanned in an Wild Aviograph B 8 S and, after an aerotriangulation, absolute orientated numerically. A digital terrain model of the whole area is established to form the base, partly of calculation of contourlines for automatic plotting, and partly of production of control data for the orthophotoprojector, Wild Avioplan OR 1.

Data-handling and control, accuracies and typical errors are discussed.

Introduction.

In the summer of 1977 the Geodetic Institute of Denmark (GID) obtained government approval for topographic mapping of the entire area of northern Greenland. The region of current interest covers approximately 300,000 km^2 of northern Greenland, that is, from the northernmost point at 84^oN down to 78^oN on the western coast, and all the way down to 76^oN on the eastern coast.

Previous to this project the area was virtually unmapped, that is in respect of generally expected map quality. As an example, the 1:250,000 AMS maps, produced by U.S.Army Map Service shortly after World War II, contain errors of up to 30 km in absolute location, and scale errors of up to 20 %. These maps are mainly based on uncontrolled photomosaics and have till now formed the best available total coverage of the area.

Prerequisites.

The geodetic field work in North Greenland is very expensive and time-consuming, due to the logistic and climatic conditions. The area is absolutely uninhabited and transversed by wide glaciers and deep fiords, which severely limit access. The expeditions have to be self supporting in both general supplies and transportation facilities, and since the area is only accessible during two months in the summer each year, the geodetic measurements for ground control are bound to be a long-winded operation.

A traditional map compilation cannot be initiated before the necessary control points are available, that is until all of the geodetic ground measurements and the subsequent aerotriangulation are successfully completed. Furthermore a conventional linemap will mainly consist of nothing but coastlines, ice boundaries and contourlines, considering the almost complete lack of vegetation and the absence of manmade objects.

Under these conditions and due to the fact that the primary users of the maps are geologists, the GID has decided that the maps be produced as orthophotomaps on a scale of 1:100,000 and with superimposed computerized contourlines. The advantages of preserving photographic details within the final maps, are obtained by the use of orthophotos as map basis.

Mapping Procedure Outline.

The advanced orthophoto technique involved is purely digitally controlled, and the computer guidance of the orthophotoprojector is based on a digital terrain model, which is used for the calculation of contourlines as well. Taking the full consequence of the demand for computerization, digitized photogrammetric measurements are carried out in relative orientated photogrammetric models only. The photogrammetric observations are numerically transformed to the ground coordinate system through a spatial transformation. This is done concurrently with the availability of coordinates to the control points and tie points, calculated by aerotriangulation.

This procedure, called the inverse mapping procedure (Dueholm 1979), provides us with the possibility of starting up the photogrammetric measurements without having to wait for the final coordinates of the control points. Consequently the photogrammetric models can be measured concurrently with the progression in the planning of aerotriangulation, that is when tie points has been selected and transfered into the photographs.

Photoflight.

A complete coverage of excellent panchromatic vertical aerial photographies was already available for the total area of northern Greenland. These wide angled photographies are on a scale of approximately 1:54,000 and they were taken during missions in the period of 1959 to 1971.

The total amount of photogrammetric stereo models will be close to 8000, using these photographies.

In order to reduce the number of photogrammetric models to be measured, it was decided to carry out a rephotographing of the whole area, and this time at the smallest accessible scale ratio. The photomission was carried out during summer 1978, and thanks to extremely lucky weather conditions the job was successfully completed within the narrow time limit.

The photography was performed by the Mark Hurd Aerial Surveys Inc., using a Gates Lear Jet 25 C. By setting the flying height to 47,000 feet (app. 14 km) and using a super wide angle camera (Wild RC 10, c=88 mm) an image scale of 1:150,000 has been achieved. In the attempt to avoid blind areas, caused by the precipitous mountainsides in combination with the use of a super wide angle lens, the photographs were taken with a length-lap of 80 %, and a side-lap of 40 %. This coverage results in a total number of stereoscopic models of about 1300.

As the aircraft has the facility of having two cameras on board, a second camera loaded with colour-infrared film was installed. A wide angle camera was chosen for this installation, resulting in CIR-photographies (false-colour photographies) on a scale of 1:87,000. As the two cameras had to expose simultaneously the CIR-photos has a length-lap of 67 % and a side-lap of 0 %. The CIR-photos were especially taken for the purpose of geological photointerpretation, and will form a valuable support for future geological mapping.

Control Points.

The rugged topography of the northern Greenland area exerts decisive influence on the choice of methods for both geodetic field work, and for the subsequent computations as well. The topography split the area and divides it into irregular model blocks for aerotriangulation. Within these blocks it is practically impossible to survey a control point system, which complies with the normal demands on control point distribution in aerotriangulation blocks. Furthermore it is practically impossible to signal any point in the field before photography, so control points have to be natural points, interpreted in the photographs during field work. Tie points have to be artificial points.

Point identification from field to photographs, and from one photograph to an other, may be very difficult. This is mainly due to the low sun angle, and to the terrain texture itself. The low sun angle causes areas of distinct difference in photographic density, and the texture causes these areas to be of low contrast. The identification procedure is further complicated due to the use of the super wide angled camera. In such photographs the very same details can be depicted having such a difference in actual visual angle, that a precise recognition can be difficult.

These are of course conditions influencing the general accuracy of aerotriangulation, but far more fatal is in fact the very nature of the artificial points. The points are marked into the photographs by drilling a 40 micron wide hole in the emulsion, performed on a Wild PUG IV point transfer device. As these holes not always seems to be strictly circular, and as the mechanical drilling procedure itself may cause small movements of the photographs during the drilling, errors can easily be introduced already at this early stage. Extreme precautions must be taken to avoid this, and the point transfer device must be verified carefully.

In order to keep down error propagation, every point to be transfered to a adjacent photograph is always transfered from the first, originally drilled point. So in fact none of the artificial points are transfered from a previous transfered point.

Image coordinates of control points and tie points are measured on a monocomparator, Carl Zeiss PK 1.

As the terrain is very mountainious, including extreme height differences, a spatial adjustment system is absolute necessary. The calculation system must be able to utilize any available field measurement for stabilizing the adjustment, in order to compensate the block irregularity. The aerotriangulation program is designed to handle quite big aerotriangulation blocks, normally 300 - 400 photographs, but up to about 2000 photographs can be adjusted. This implies the necessary bridging across the permanently snow covered regions, in which field measurements as well as photogrammetric observations are unfeasible, and redresses further the consequences of the block irregularity.

In fact the GID has built up a complex computer program system for aerotriangulations. Both for handling simple model and strip connection, including a polynomial adjustment, and for handling block adjustment of independent models as well. These programs are accomplishing the utmost important task of initial error search and correction, and provide preliminary coordinates and orientation parameters for the final bundle adjustment as well.

The basic control point system consists of a number of Doppler-stations, surrounding the actual area of present blocks, within the range of the expedition of the year. As far as possible, the Doppler-stations are situated at easy recognizable sites, having a mutual distance of 40 - 60 km. In the central parts of the area, complementary Doppler-stations are established to the greatest extent within the limited time available.

The height control consists of barometric height measurements for every 30 km, ensuring one height observation per 1000 km^2. Moreover traditional geodetic measurements, such as distance measurements, intersections, etc., are performed in connection with the procedure of moving the Doppler instrument. Furthermore gravity measurements, sea level observations, etc. are performed, to accomplish not only the strictly necessary, but the most adequate observation basis.

Our germinating experience tells that on this basis we can produce control point coordinates (tie points) with a mean square error of about 4 meter (23 micron in image scale) as a result from the bundle adjustment. It seems that the tie points are marked in the photographs with an estimated accuracy of 20 micron.

This astonishing fine quality of the control points, combined with the considerable number of control points of about 10 - 12 within each photogrammetric model, provides an excellent foundation for the successive model profiling, and thereby for the computation of orthophotos and for the calculation of contour lines.

Data Acquisition.

The data acquisition is performed in a Wild stereoplotter, B 8 S, equipped with an tri-axis locator, a coordinate registration device, EK 20, and a scanning equipment, PEB 8.

The stereoscopic model set up in the instrument, will be relative orientated, made approximate horizontal, but no absolute orientation is needed. Threedimensional model coordinates to points located in a square grid, will be recorded. The grid equidistance is set to 3.00 millimeter in the model scale (1:75,000), equivalent to approximately 225 meter in the terrain.

Profiling is the most convenient, and probably the only practicable method for systematic data acquisition in a photogrammetric instrument. Besides, spot heights obtained in a square grid will form a nearly optimal description of the terrain, according to the consideration of the terrain as a stochastic process. This point configuration will ensure a terrain description with homogeneous distribution of information, and an average content of information per point, which is nearly optimal terrain descriptive.

Additional to the scanning of a model, shore lines and single points of special significance are recorded. These supplementary single points are selected by the photogrammetric operator, in order to complete the terrain description. Points of local extremes and points in areas of dense shadows, in which the scanning is difficult, are typically recorded.

The complete photogrammetric measurement of a model amounts to a total of approximately 7500 recorded points, and a total duration of about 8 hours. So only one model can be measured within a working day, using one photogrammetric instrument. The scanning of models alone determines the total duration of this project to be of about 6 - 8 years, still on the assumption that only one photogrammetric instrument is used.

Data Control.

For the present the utmost necessary control of data is carried out on the main computer of the GID. These calculations are done to expose errors in the photogrammetric instrument and/or the registration equipment. Also operator introduced errors, such as blunders in the data descriptive record or real measuring errors, are hopefully exposed.

It is controlled, that the preset number of profiles, and the expected number of points within each profile are present, and whether the x- and y- coordinates of the recorded points really form a square grid. The z coordinate is controlled by means of interpolation filters. This control is completed by a visual inspection of plotted contours, roughly calculated in the model coordinate system.

Digital Terrain Model.

The digital terrain model (dtm) shall form the basis for interpolation of contourlines and for calculation of control data for the production of orthophotos.

The dtm are to consist of discrete points situated in a square grid, in the ground coordinate system.

As both the mentioned tasks involve linear interpolation between the calculated dtm-points, a grid interval of 1.00 millimeter in the map scale, corresponding to 100 meter in the terrain, is considered to be quite sufficient.

On the basis of the transformed photogrammetric measurements, the task is to describe the topography between the recorded points, so that heights of arbitrary points can be calculated without critical loss of accuracy.

The interpolation method chosen for this project, is the linear prediction. This method does not require the observations to be located in a perfectly square grid, and this particular quality is of vital importance for an inverse mapping procedure, since the original grid of observation points is slightly deformed during the numerical absolute orientation. In the general version the method of linear prediction requires considerable computational resources, but the regularity of the sampling pattern, permits us to introduce some simplifications. The method is based on an analysis of the correlations between points in the terrain, and will not be described in details in this paper, but some of the implemented simplifications are listed.

- In the interpolation of a dtm-point, only the 16 points located in the immediate vicinity are taken into consideration. These 16 points form a computing unit, which are stepwise displaced through the observation grid, to ensure the continuity of the calculations.
- The trend surface for each computing unit will be approximated by a plane, determined by least square adjustment.
- For areas of uniform morphology a common correlation function is used in the treatment of the trend-reduced observations within the computing units.
- The configuration of the points within the individual computing unit is presupposed identical for all computing units.
- As a consequence of these assumptions, the correlation matrix can be derived from a general correlation function, and inverted once and for all within each photogrammetric model.

The remaining calculations are thus reduced to the determination of the trend plane for every computing unit, and the cube of 16 multiplications for each individual point to be interpolated.

Data Banks.

A systematic data storing and retrieval system is important in any digitized mapping procedure, and essential for handling large numbers of data. For an inverse digitized mapping procedure involving huge data quantities, the problem of data storage becomes of vital importance. In fact the data storing system is the very crux of the total project, not only to serve the actual requirements, but certainly to make the condensed information available in future for various purposes and for different users as well. Consequently considerable effort has been laid down in designing the data bank system.

In accordance with the dissimilarities in both content and organization structure, we consider it expedient to distinguish between the following three types of data banks.

Observation banks, containing original observations. The data are stored in the sequence of the measuring process, and retained in the local coordinate system, (i.e. image coordinates, model coordinates, etc.). Separate banks are established for handling the different types of observations (geodetic observations, photogrammetric observations of various kind) and divided into sections of coherent observation data. Due to the measuring procedure, the sections are often further split into segments of informatively coherent data, such as profile-data, groups of single points and shore lines.

Universal banks, containing processed data in a systematized form, and transformed into a common universal coordinate system, e.g. UTM-coordinates. Even though just one great universal bank in fact can hold all final processed data, this configuration will not be desirable. Separate banks are therefore established for groups of uniform topics, such as control points, interpolated dtm-heights, etc.

Thematic banks, typically containing data extracted from the other banks. During the selection, or by a special processing, some parts of the original information will be strongly emphasized and other parts will be suppressed or completely omitted. The thematic banks can be rather similar to the universal banks as regards data substance, but of course dedicated a specific theme, e.g. shore lines.

In order to secure the management of all these data, and of the necessary provisional and intermediate data-files as well, we have designed a general header record, for all data set within this project. The header record contain, in a fixed format, an unambiguous description of the containment and the organization structure of the actual data file.

As an example of structure and organization of a data bank, the height data bank shall be briefly mentioned. The bank contains calculated spot heights, interpolated by the dtm-program, of points located in a square UTM-grid, in the actual UTM-zone. Data within the bank are organized in geographic sections of about 4200 km^2, containing roughly 400,000 points. For each point the z coordinate, a quality describing figure (e.g. mean error, weight, etc.) and the date of calculation is stored. Introductory to each section, basic information is stored to describe the geographical location and size, that is coordinates of the point of local reference, and the number of points in the two directions of the grid (rows and columns). The x and y coordinates are omitted, as these values easily can be derived from the sequential order of the points, the grid spacing and the coordinates of the reference point.

The data bank for the total project becomes very comprehensive. We expect the total number of interpolated points to amount to approximately 50 million, demanding about 200 magnetic tape reels. A superior management disc-file has been established, containing key data for all sections, such as geographical location and size, physical location (tape reel identification number) and extent, etc. The management file is automatically updated by the updating process of the data bank.

By using this structure, combined with an almost foolproof updating procedure, we hope to have established an effective data storing system of adequate flexibility.

Calculation of Contour Lines.

When point-strings forming contourlines are to be calculated, the grid of dtm-points is divided into triangles by diagonals. Each triangle is regarded as a plane to represent the terrain surface between the points. Because of the chosen grid spacing in the dtm-points, the dimension of each triangle becomes 1.0 x 1.0 x 1.4 millimeter in the map scale. Within the individual triangle the contour line elements are unambiguously defined as a band of parallel lines from one side of the triangle to an other. Coordinates to the points of intersection between these lines and the sides of the triangle, are therefore easy calculated by a simple linear interpolation. The remaining problem is reduced to the administration of the crowd of contour line segments, in the process of joining them into continuous lines.

The limited capacity of our computer has forced us to perform a stepwise calculation by dividing the area of computation, e.g. a map sheet, into computing units. We have decided upon a unit size of 20 x 20 points as suitable to meet the requirements, but other unit sizes can easily be implemented. The computation is carried out by a procedure of sequential calculation of coordinates within the computing units, frequently interrupted by the joining process, in a multi level hierachy.

By the use of this strategy it is possible to calculate contour lines for a whole map sheet on a small size computer, provided the sufficient backing storage area is available.

The formation of triangles results in a variable density of points within the calculated contour lines. This particular point distribution is not supported by the density of the dtm, not a reflection of specific information, but purely invented by the chosen division into triangles. So a more representative selection of points to form the contour lines would be prefererable.

Smoothing of Contour Lines.

For cartographic reasons, i.e. to get a less computer-like product, it will be appropriate to perform some smoothing of the calculated contour lines. This will also reduce the effect of the small bends introduced by the simplifications in the linear prediction. The final selection of points for the drawing process, can then take place in the smoothed lines, and thereby become graphically representative.

The smoothing of contour lines can be done in various ways, manually as well as digitally. The manual way is very time consuming, but almost unproblematic. The cartographer is capable of perceiving a whole terrain region and therefore to smooth the contour lines taking into consideration the immediate vicinity of the line and its neighbours, resulting in an optimal graphic representation of the terrain.

An automatic computerized smoothing is quite the opposite. It is almost impossible to obtain a general view, and the treatment of the coordinate string, describing a single contourline, is very laborious. Substituting the contourline with a mathematical function, $f(x,y)=0$, will normally force one to sectionize the line and to use several functions for the complete description. If the number of functions involved is reduced, the bends where two different functions meets will be increased.

We have not yet decided on the smoothing method to be used, but we have implemented a adequate solution for preliminary experiments. This method is based on dividing the contourline coordinates into x- and y- components by the parameter functions $x=x(t)$ and $y=y(t)$, (Nakamura as described by Linkwitz). In this way the original complicated contour line is reduced to a simple mathematical representation. The two independent parameter functions are then to be Fouriertransformed, and the resulting degree of smoothing is controlled by means of the number of included Fourier parameters in the mathematical reconstruction of the contour line, i.e. by fixing the minimum wavelength within the Fourier expression.

Generalization.

A generalized terrain surface can be described by means of contour lines, which often are called "generalized contour lines". In this case the generalization is introduced in connection with the calculation of the digital terrain model, and can easily be accomplished by using a suitable correlation function.

Smoothing of contour lines, as mentioned above, does not imply any kind of generalization of the surface, only a smooth line.

Generalization is not of current interest within this project, but can be for future production of maps, derived from the present production.

Production of Orthophotos.

The orthophotos form the basis for the subsequent cartographic work, and are produced on a Wild Avioplan OR 1. Control data for the orthophotoprojector are computed by the SORA-program, supplied by the Wild company.

The data necessary for this production have already been mentioned: image coordinates, terrain point coordinates, coordinates for the projection center and the camera orientation, and they are all stored in data banks, ready for use.

Management software has been developed to collect all relevant data from the respective data banks, and provide them with a suitable format to meet the requirements of the SORA-program.

At present the computing time is about 30 minutes, using a 5 millimeter slit length on the OR 1, and the production time at the OR 1 is about 20 minutes, for every orthophoto.

The Final Maps.

The cartographic design phase of the end product is still not completed. Orthophotomaps is until now not in common use in Denmark. We have no traditional restrictions in design of orthophoto maps, and a variety of possibilities have been considered.

One map sheet consists of 16 - 20 orthophotos, which will be merged along straight lines without any kind of retouche. Nor will any attempt be made to equalize the dissimilarities between adjoining orthophotos, mainly caused by different time of exposure, e.g. differencies in shadows, snow coverage, etc.

Glaciers or waters outside the photo coverage, will not be completed.

Maps will be published in two versions concerning different grid combinations.

Geographical names as well as signatures for manmade objects, will be applied.

Contour lines, at intervals of 50 or 100 meter depending on the local terrain slope, are superimposed the screened image in a transparent colour, preventing the lines to hide essential image information.

The first sheet is planned to be published during 1981.

Conclusions.

At the very start of this project, there was neither tradition nor experience for digital mapping at the GID. It seems appropriate to make a kind of status of the first 18 month of the project.

- The aerotriangulation proceeds satisfactory almost without problems, exept for the point transfer device, which have to be verified quite often.

- The scanning of models have caused serious problems. The instrument (Wild B 8 S) has been operational for one year, and in this period about 25 % of the measurements have been rejected mainly due to hardware failures, with only 3 - 5 % due to actual errors in the measurements. This percentage of error has forced us to purchase a desktop calculator, HP 9825, and a small plotting table, in order to carry out on-line monitoring and preprocessing of data. This includes profile control, data reduction and compression, plotting of temporary contours and recorded shore line elements. The tape station of the PEB 8 will be put under direct control of the HP 9825, whose built-in casette tape station can be used for back-up. It is our hope that the graphic monitoring will be helpfull to the operator in the measuring process by visualizing the recorded items.

- Concerning the production of orthophotos, several problems have been encountered. In the first place seems our FORTRAN compiler to be rather poor, and several compiler errors has been detected during the implementation of the SORA program. (The main computer at the GID is supplied with an excellent ALGOL compiler, and all home-programming is performed in this language.). At present the program is still not working satisfactory, and we can not recommend implementation on a computer, different from the type of computer originally used for the program development. As soon as possible, a quite new program will be developed at the GID to replace the SORA-program. An other problem concerns the very design of the OR 1. The basic assumption in the OR 1- philosophy is terrain approximation by straight line elements. The dimension of the line elements is fixed by the slit length of the OR 1. The minimum slit in the standard delivery is 5 millimeter, which in our case corresponds to 500 meters in the terrain. The assumption of terrain linearity is indeed not valid for a North Greenland area of that extent, but the effect of the hereby introduced errors can be reduced by decreasing the slit length. As the computing time of the SORA-program is inversely proportional to the square of the slit length, the time consumption will increase drasticly on decreasing the slit length.

- The very structure of the terrain is the cause of some functional problems, concerning the operation of the orthophotoprojector. From sea level the cliffs rise to a height of 800 - 1000 meter within a few hundred meters. This forces the zoom lens of the OR 1 to move so rapidly, that it eventually gets into an alarm condition, unless the scanning speed is set to a minimum. Blind areas where no image is available for projection may cause a severe alarm, preventing the orthophotoproduction within this particular area.

- The alarm messages of the OR 1 are rather poor. The single word "alarm" is printed on the console, and this message is really of no use, since the OR 1 already has stopped.

- The success of a project like this is very much dependent on the photogrammetric operators, and no attempt to improve the instruction and education, and to minimize the alienation of the operators, should be untried.

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