A PHOTOGRAMMETRIC MONOPLOTTER FOR DIGITAL MAP REVISION USING THE IMAGE PROCESSING SYSTEM GOP-300.

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ABSTRACT

For revision of maps and location of test areas for remote sensing, a monoplotter was developed to be run on the digital image processing system GOP-300. Arbitrary sized images and maps are stored in digital form on disk and are displayed using roaming functions. The relations between image and map pixel systems are determined using standard photogrammetric procedures and a digital elevation model.

The monoplotter has been provided with a user interface including the possibility to remeasure points for orientation of the image and map. Automatic identification of ground control points and of fiducial marks are investigated using the possibilities inherent in the image processing system GOP-300 as well as the Foerstner interest operator together with known geometrical information of the points.

1. INTRODUCTION

The production of maps is to a large extent becoming dependent on high speed computers with possibilities of storing large volumes of data. The use of photogrammetric methods has a long tradition in map production, but it has only recently become possible to store complete aerial photographs at the required resolution. As soon as this is possible, it is tempting to use the computer for various photogrammetric tasks in the mapping procedure. Examples of such problems are the orientation of aerial photographs and automatic identification of objects such as fiducial marks, ground control points, buildings, streets, etc. Special purpose computers, the image processing systems, have turned up making the computer time needed for solving some of these problems acceptable. With these systems at hand it is possible to construct integrated procedures for image handling and map construction.

The ContextVision system GOP-300 is an image processing system which can be used for both general image handling tasks and more specific photogrammetric procedures. Image handling procedures, i.e. procedures working pixel by pixel, are handled in special purpose processors as for instance filter-, floating point- and geometrical processors. Other types of tasks, for instance estimation of parameters in well defined procedures such as inner and outer orientation of images can be solved in

the host computer (Motorola 68000) using an ordinary high-level language (C, Pascal or Fortran).

At the department of photogrammetry at the KTH in Stockholm, various methods for simple and efficient map construction have been developed during a number of years, see e.g. Östman (1986). In order to evaluate the possibilities of using a ContextVision GOP-300 image processing system for classical photogrammetric standard procedures, an analytical monoplotter was developed during the autumn 1986. The program was written in Pascal and was planned to have a well developed user inter-face in order to make it possible to use the program in a practical production situation. The program was further developed during 1987-8 improving the user interface making it possible to remeasure single points in the orientation procedures and also automation of these procedures.

The present version was tested using complete black and white aerial images of size up to 23 * 23 cm with a pixel size of 25 µm corresponding to some 85 Mbytes storage requirements. As there is no digitizing table available in the system at hand, the program was developed to display the map in the same way as the aerial photograph with a possibility of fast switching between image and map. Full use is made of the possibility to roam in both image and map so as to be able to obtain maximum quality in point definitions.

2. THEORETICAL BACKGROUND AND WORKING PRINCIPLE

A model for the monoplotter consists of an image, a map and a DEM together with appropriate information to determine the necessary orientations. After an initial inner and outer orientation of the image, the map is oriented. The plot direction (image → map) or (map → image) is then chosen by the operator. Points, polygons or continuous curves can then be drawn in the image (map). By an indication of the operator, a transformation to the map (image) system is performed and the corresponding points, polygon or curve is drawn in the map.

3. DIGITAL ELEVATION MODEL

When points on the ground and points in the image are to be related, ground elevation values are necessary. These are calculated using a digital elevation model, a DEM. This should be supplied in the form of a regular grid, oriented parallel to the axis of the geodetic system, and having a constant grid point interval, common to the x- and y- directions. Each point in the model is represented by X-, Y- and Z- coordinates.

Points can be missing in that the Z-coordinate or all three coordinates are missing. In the latter case room is made in the model for the missing point by introduction of X- and Y-coordinates at the appropriate place. The model is then

searched for missing Z-values which are determined as the mean of those adjacent points in the X- and Y-directions which are present. If no adjacent points exist, the operator is informed and the program exited. After preprocessing the DEM in this way, the elevation at an arbitrary point (X,Y) within the DEM is determined by bilinear interpolation.

4. INNER ORIENTATION

The relation between the coordinate system of the displayed digital image and the camera system is established in an inner orientation procedure. Coordinates in the digital image are given as (row-number, column-number). The camera system is defined by the camera constant and the coordinates of a set of fiducial marks.

The operator can choose between two different procedures when collecting the necessary information for an inner orientation. The first alternative is to point at the fiducial marks one at a time using the cursor. The inner orientation is then determined using the obtained coordinates to establish an affine transformation.

The second alternative makes use of the special advantages of a digital image processor and is completely automatic. Fiducial marks are generally different in different cameras. However, they usually have a well defined appearance and occupy an extended area devoid of other information. Their degree of symmetry is high and their approximate location in the image known in advance. They can therefore easily be identified using template matching and then localized with center of gravity methods.

A procedure for locating objects in an image usually admits the possibility of the objects having completely arbitrary locations. Every pixel is then a candidate for the location. The images discussed here are typically of the size 1-100 Mbytes. As a consequence, the time used for the location of an object is large even when using special hardware (a few minutes up to several hours). These times have been avoided by requiring that the fiducial marks should ly within certain prescribed subareas of the image, presently one fiducial mark within each corner window of the image. A corner window and the total image have one corner in common. The size in pixels^2 of the corner window is $(51200/n)^2$ where n is the sampling interval given in microns.

The procedure for the automatic inner orientation of a given image is now

1) The four corner windows are copied from the image disc file to four different image registers according to the rules above. At the same time they are subsampled by a factor $100/n$ so that the images in the registers have size 512^2. In this way the size of the fiducial marks is independent

of the sampling interval.

2) Each of the four image registers is filtered using a template containing the fiducial mark (or anything highly correlated with it) as kernel. At the same time trace is kept on which pixel gives the strongest output. The location of this pixel is used as an approximate location for the fiducial mark at hand.

3) Given the approximate locations of the four fiducial marks, these marks are now copied from the original image into prescribed places in a common image register. Finally their location is determined from a center of gravity estimation.

4) The parameters describing the inner orientation are now determined using the so obtained final coordinates to establish an affine transformation.

The following information on the inner orientation is displayed:

● The coordinates of the image origin in the camera system defined as the fiducial center (x'_0, y'_0).
● The largest scale factor A and the corresp. direction α_A.
● The smallest scale factor B and the corresp. direction α_B.
● The affine property in per cent, ie the value of $100*(A/B-1)$.
● The rotation angle β between the image screen system and the camera system.

The quantities A, B, α_A, α_B, β are determined by regarding the affine transformation as a stretching in the directions $\alpha_A = \alpha$ and $\alpha_B = \alpha + \pi/2$ followed by a rotation β:

$$
\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{bmatrix} \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} A & 0 \\ 0 & B \end{bmatrix} \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix}
$$

$a_{11}, a_{12}, a_{21}, a_{22}$ are the coefficients of the affine transformation. They are determined in the least square sense, i.e. by minimizing the sum of squares of the discrepancies ε_1, ε_2, according to the following relations:

$$
\begin{bmatrix} x'-x'_0 \\ y'-y'_0 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} u-u_0 \\ v-v_0 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix}
$$

The following notations are used:

(x',y') coordinates of a fiducial point in camera system.

(u,v) coordinates of a fiducial point in image screen system.

(x'_0, y'_0) means of all (x',y'). Fiducial center of camera.

(u_0, v_0) means of all (u,v).

The least squares solution is as follows:

$$A = 0.5 * \left[\sqrt{[(a_{11} + a_{22})^2 + (a_{21} - a_{12})^2]} + \sqrt{[(a_{11} - a_{22})^2 + (a_{21} + a_{12})^2]} \right]$$

$$B = 0.5 * \left[\sqrt{[(a_{11} + a_{22})^2 + (a_{21} - a_{12})^2]} - \sqrt{[(a_{11} - a_{22})^2 + (a_{21} + a_{12})^2]} \right]$$

$$\alpha_A = 0.5 * \{ \beta + \arctan[(a_{12} + a_{21})/(a_{11} - a_{22})] \}$$

$$\alpha_B = \alpha_A + \pi/2$$

$$\beta = \arctan[(a_{12} - a_{21})/(a_{11} + a_{22})]$$

5. OUTER ORIENTATION

The relation between the camera system and the geodetic coordinate system is determined in an outer orientation procedure. Denote

c camera constant

$[r_{AB}]$ rotation matrix involving the angles ω, φ, κ

(X_0, Y_0, Z_0) place of exposure in the geodetic coordinate system

(X, Y, Z) geodetic coordinates of a ground control point

The colinearity relations

$$x' = F_x(\omega \; \varphi \; \kappa \; X_0 \; Y_0 \; Z_0) = -c \; \frac{(X-X_0)r_{11} + (Y-Y_0)r_{21} + (Z-Z_0)r_{31}}{(X-X_0)r_{13} + (Y-Y_0)r_{23} + (Z-Z_0)r_{33}}$$

$$y' = F_y(\omega \; \varphi \; \kappa \; X_0 \; Y_0 \; Z_0) = -c \; \frac{(X-X_0)r_{12} + (Y-Y_0)r_{22} + (Z-Z_0)r_{32}}{(X-X_0)r_{13} + (Y-Y_0)r_{23} + (Z-Z_0)r_{33}}$$

are linearized in all six variables. In this way a linear system of equations is obtained consisting of two equations for each ground control point and involving the unknowns ($\delta\omega$, $\delta\varphi$, $\delta\kappa$, δX_0, δY_0, δZ_0) = $\underline{U}$. If a sufficient number of ground control points are supplied, the system is overdetermined. Writing these equations as

$$A\underline{U} = \underline{V},$$

the unknowns are determined in the least square sense, by

solving the normal equations (A' is the transpose of A):

$$\underline{U} = (A'A)^{-1}A'\underline{V}$$

Initially, coordinates of the n ground control points up to a maximum number of 17 are measured in the image and transformed into coordinates (x',y') of the camera system, using the inner orientation parameters obtained in the previous section. The mean of the X- and Y-coordinates of the ground control points together with the sum of the mean flying height and the mean terrain height are chosen as initial values of the coordinates for the place of exposure. The angles ω, φ, κ are given the initial values O. There is also a possibility for the operator to choose initial values. The unknowns are determined in an iterative procedure.

The outer orientation parameters are obtained from the initial values by successively adding the unknowns from each iteration. The procedure is terminated when the sum of squares of the unknowns is small enough, or after a maximum of 10 iterations. Finally the precision s in the estimated vector (ω φ κ X_0 Y_0 Z_0) is calculated as

$$s = \sqrt{\left[\frac{\underline{V}.\underline{V}}{2n-6} \, \text{diag}\{(A'A)^{-1}\}\right]}$$

When collecting the coordinates for the ground control points from the displayed image, the operator can choose between several different procedures. One alternative is to point at the ground control points in the image, one at a time, using the cursor. The obtained coordinates are then used in the outer orientation procedure described above. In this alternative a list with the points to be used must be prepared in advance.

The procedure just described is quite time consuming due to the fact that the operator must switch between a total overview of the image and windows containing the ground control points in full view. In order to speed up the procedure, a second alternative was developed. Here the operator gives the names of two ground control points and then points at these in the displayed image. Using the known locations of these marks in the ground system and in the image together with the known locations in the image of the fiducial marks, the monoplotter program then scans a global list of ground control points selecting those points contained in the image. Windows containing the ground control points are then displayed on the screen, all in one view. The operator then points with the cursor at those control points which are intended to be used in the outer orientation. A center of gravity determination in a small window containing each selected ground control point then gives the final location of each point. The obtained coordinates are then used in the outer orientation procedure described above.

In a third alternative the procedure described in the previous section has been partly automated. The choice and identification by the operator of the first two ground control points is

carried through as before. The pointing with the cursor at the
remaining ground control points in the different windows has
been exchanged for an automatic identification procedure. The
windows are processed using the Förstner interest operator,
giving high output at small features of high circularity and
low output otherwise. The windows being small (some 100^2
pixels) and containing one ground control point each, the
location of the maximum output is taken as an approximate
location of the point. The final location of each point is
obtained as previously described, i.e. in a center of gravity
determination. This alternative has just been implemented.
At the submission of this paper, problems still occur with
selecting the correct points when these are week. Experiments
are still going on with choosing appropriate window sizes and
cutoff parameters for the interest operator.

A further question is if also the identification of the two
first ground control points can be dispensed with, this
resulting in a completely automated inner and outer orientation
of the image. Although the time necessary for running image
operations range up to several hours for 100 Mbyte-images, it
is in principle possible to identify candidates for ground
control points by processing the total image using the Förstner
interest operator. The output of this operation is a list of
coordinates suggesting locations of ground control points. This
list is recompiled into a list of ordered distances between all
possible point pairs with the greatest distance first, the
C(andidate) list. The list of known coordinates of ground
control points is compiled in the same way, giving the P(oint)
list of ordered distances between actual ground control points.
Now proceed according to the following scheme:

Starting with $p=1$, for the p:th distance in the P-list, perform
the following operations on the C-list:

1) Starting with $c=1$, in the c:th step, all distances with
   index $> c$ in the C-list are normalized in such a way that
   the c:th distance is equal to the p:th distance in the
   P-list.

2) The p:th distance in the P-list is the distance between two
   points A and B with elevations h_A and h_B. After deleting
   distances with index $< c$, the C-list is scanned for
   distances close to distances in the P-list after corrections
   for first h_A and then h_B. An overall measure of fit is then
   determined for the selected distances.

3) For some instance $p=p_0$ and $c=c_0$, the p_0:th distance in the
   P-list and the c_0:th distance in the C-list actually
   correspond. The normalization of the distances in the C-list
   and the correction for one of the heights h_A and h_B then
   have the effect that all distances common to both lists are
   almost equal. The measure of fit is therefore a good
   indicator of the correct solution.

This procedure results in a list of points in the C-list

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corresponding to a subset of points in the P-list. The coordinates of these points are used as approximate values in a procedure for final localization of the ground control points using a centre of gravity estimation. However, at the time of submission of this paper this final alternative has not yet been implemented.

6. MAP ORIENTATION

The relation between the coordinate system of the displayed digital map and the geodetic system of the ground control points is determined in a map orientation using the same procedures for affine transformation as in the inner orientation procedure. Coordinates of the digital map are given as (row-number, column-number). The following result of the orientation is displayed:

- The location of the map origin in the geodetic system defined as the sum of the coordinates of the ground control points.
- The largest scale factor A and the correspond. direction α_A.
- The smallest scale factor B and the correspond. direction α_B.
- The affine property in per cent, ie the value of $100*(A/B-1)$.
- The rotation angle β between the map system and the geodetic system.

For definitions of these quantities, see the section on inner orientation.

7. PLOTTER

When the image and map have heen oriented, the plotter can be run. If these procedures have been carried through in a previous run, it is possible to go directly for the plotter. The operator is offered the choice of drawing points, a polygon or a continuous curve. It is possible to draw in both directions, i.e. to either draw in the image and let the plotter transform the drawing into the map or vice versa.

When plotting in the (map → image) direction, the transformation from (X,Y,Z) in the geodetic system to (x',y') in the camera system is performed using the exact relations for x' and y' given in the section on outer orientation.

When plotting in the (image → map) direction, the calculation of (X,Y,Z) in the geodetic system from (x',y') in the camera system is performed in an iterative process according to

$$X_k = X_{k-1} + \frac{r_{11}x' + r_{12}y' - r_{13}c}{r_{31}x' + r_{32}y' - r_{33}c}(Z_k - Z_{k-1})$$

$$Y_k = Y_{k-1} + \frac{r_{21}x' + r_{22}y' - r_{23}c}{r_{31}x' + r_{32}y' - r_{33}c}(Z_k - Z_{k-1})$$

starting with Z_0 equal to the mean terrain height and terminating when the plane distance between successive points differs by less than the mean flying height/100000.

8. REFERENCES

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9. OVERALL SCHEME

```
              ┌─────────────────────┐
              │  MODEL DEFINITION   │ no
              │  define new model?  ├──────────────────────┐
              └──────────┬──────────┘                      │
                         │ yes                             │
              ┌──────────▼──────────┐                      │
              │  INNER ORIENTATION  │                      │
              └──────────┬──────────┘                      │
                         │                                 │
              ┌──────────▼──────────┐                      │
              │  OUTER ORIENTATION  │                      │
              └──────────┬──────────┘                      │
                         │                                 │
              ┌──────────▼──────────┐                      │
              │   MAP ORIENTATION   │                      │
              └──────────┬──────────┘                      │
                         │                                 │
         ┌───────────────▼──────────────┐                 │
         │  save orientation parameters │                 │
         └───────────────┬──────────────┘                 │
                         ◄──────────────────────────────────┘
         ┌───────────────▼──────────────┐
         │  read orientation parameters │
         │  read digital elevation model│
         └───────────────┬──────────────┘
                          │
  map → image   ┌─────────▼────────┐   image → map
     ┌──────────┤     PLOTTER      ├──────────┐
     │          │  plot direction? │          │
     │          └────────┬─────────┘          │
┌────▼─────────┐         │           ┌────────▼───────┐
│ draw points, │         │           │  draw points,  │
│ polygon or   │         │           │  polygon or    │
│ curve in map │         │           │ curve in image │
└────┬─────────┘         │           └────────┬───────┘
┌────▼─────────┐         │           ┌────────▼───────┐
│ transform to │         │           │  transform to  │
│ image and draw│        │ no        │  map and draw  │
└────┬─────────┘    ┌────▼─────┐     └────────┬───────┘
     └─────────────►│finished? │◄─────────────┘
                    └────┬─────┘
                         │ yes
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