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The Maintenance of Large Scale Maps
by Digital Mono Plotting.

Anders Östman
Department of Photogrammetry
Royal Institute of Technology
S-100 44 Stockholm
Sweden

ABSTRACT

Many Swedish municipalities have today considerable problems in the maintenance of their large scale base maps. For this purpose, geodetic measurements are usually used. One major problem in the maintenance of the base maps consists of the large number of measurements to be performed.

Digital mono plotting is a method which seems to be well suited for such data acquisition. Hasselblad MK-70 images are enlarged 5 – 10 times and digitized in mono mode, using a digitizing table. Image deformation due to the enlargement process are corrected by using a dense reseau grid. The position of the measured objects (co-ordinates and line parameters) are determined by least squares adjustments.

An accuracy test revealed a standard error of the mapped features of 25 microns in planimetry and 30 microns in height. The method seems therefore to be accurate enough for most large scale applications.

1. INTRODUCTION

During the latter years, the major task for many map production organisations has slowly changed from map production to map revision. In Sweden, the municipalities are responsible for the production and revision of large scale base maps with scales varying from 1:400 to 1:2,000 and covering city areas and other areas of economical interest. In 1984, the cost for the revision of the base maps was about 56% of the total budget for the base map. During the years to come, this part of the cost is expected to increase (Östman, 1985). The need for map revision is most pronounced in the large municipalities, but in the years to come, this need will also increase in the middle sized and small municipalities.

The maps are often produced by photogrammetric methods by consultants. The revision of the base maps, however, is often performed by the municipalities themselves. Since only one municipality in Sweden, of a total of 284, have a photogrammetric stereo instrument, the main part of the revision work is carried out by geodetic field measurements.

One central problem in the revision of the base maps is the large number of measurements needed. Automation of the geodetic field work has reduced this problem to some extent,
but it still mainly remains unsolved. Compared to field measurements, the use of aerial photographs is very effective for the detection of changes (Walker, 1984). In combination with the current lack of resources for performing the geodetic field measurements, photogrammetric methods for map revision may be useful. But such a photogrammetric method has to be based on the fact that 283 of 284 municipalities do not have any photogrammetric stereo instrument of their own. This means that unconventional methods have to be developed in order to fit the needs of the Swedish municipalities.

The purpose of this paper is to describe such an unconventional method, namely digital mono plotting and to study the accuracy that can be obtained by using this method.

During the latter years, there has also been a growing interest in map data bases. For their maintenance, data acquisition methods based on a digital technique is to be preferred. The digital mono plotting method described in this paper is one such method. However, in the remaining part of the paper, no distinction will be made whether the method is to be used for map revision or for data base maintenance.

2. DIGITAL MONO PLOTTING

The term digital mono plotting was probably introduced in photogrammetry by Makarov (1973, 1982). Here, aerial photographs are digitized using mono instruments, for instance a mono comparator or a digitizing table. The method has then been further refined by Besenicer (1978) and Masry and McLaren (1978).

In these earlier works, three-dimensional space co-ordinates were calculated as the resection between the observation vector and a digital elevation model. Since only a few Swedish municipalities so far have started to store elevation data in computers, the use of digital elevation models is not attractive for the revision of the Swedish base maps.

In the approach presented in this paper, the procedure for performing digital mono plotting is as follows. Firstly, aerial photographs are obtained, using a middle size format camera, for instance a Hasselblad MK-70. The aircraft to be used can be a conventional aeroplane, an helicopter, a model aircraft or other unconventional aircraft. For map revision purposes, the existing map or map data base can be used as ground control. In such cases, the needs for targeting is limited.

The images are then enlarged, say 5 - 10 times depending on the negative scale and the scale of the map to be revised. By comparing a transparent version of the map with an enlarged photograph of the same scale, mismatches are easily detected.
Geometric distortion, due to the enlargements process, has to be corrected. In this procedure, a dense reseau grid is used. The measurements are then performed using conventional digitizing tables. Finally, the three-dimensional coordinates are computed by least squares adjustments. This provides a good control of the geometric as well as the stochastic model. The advantages of using least squares techniques are, among other things, that the theory is well developed and that the whole machinery of statistic facilities such as data snooping and a posteriori weight determination can be used to improve the result.

3. BASIC GEOMETRIC MODELS

The use of mono viewing instruments is rather well-known for many photogrammetrists. Mono comparators are for instance often used for aerial triangulation. In such cases, the basic idea is that clearly visible point objects, such as targets, are measured. The three-dimensional co-ordinates are then calculated by a least squares adjustment. The basic geometric condition used in this type of aerial triangulation is the collinear condition

\[ \bar{x}_p = \bar{x}_0 + \lambda \cdot R \cdot \bar{x} \]  

(1)

where \( \bar{x}_p \) is the space co-ordinates of the point object
\( \bar{x}_0 \) is the position of the projection centre
\( \lambda \) is a scalar
\( R \) is a rotation matrix
\( \bar{x} \) is the image co-ordinates of the object.

The collinearity condition expresses the fact that the object point, its projection on the image and the projection centre are located along a straight line. To solve the equation system, the same point object has to be measured in at least two different images.

The collinearity condition as expressed in eq. 1, is subjected to point determination. For line objects, however, it is very difficult to measure the same point in different images without using stereo vision. To solve this problem, the left hand side of eq. 1 may be expanded as

\[ f(\xi) = \bar{x}_0 + \lambda \cdot R \cdot \bar{x} \]  

(2)

where \( \xi \) is a vector with parameters
\( f(\xi) \) is a parametric description of the object.

If the measured object is a straight line, this equation becomes
\[ \bar{x}_b + \tau \cdot \bar{u} = \bar{x}_0 + \lambda \cdot R \cdot \bar{x} \]  

(3)

where \( \bar{x}_b \) is a base point of the line object

\( \bar{u} \) is the direction of the line

\( \tau \) is a scalar.

The scalar \( \tau \) determines the measured points uniquely and are in general of less interest. To reduce the equation system, standard least squares techniques can then be used.

Depending on type of object, the geometric conditions of the observations vary. As a general rule, an object has to be measured in at least two different images. But to avoid singular equation systems, other geometric restrictions may also have to be considered, such as large overlap between adjacent strips. But due to the general least squares formulation of the problem, it is not necessarily the same point that has to be measured in the different images. It is enough to measure the same line, which can easily be done using mono viewing.

An alternative description of this approach can be made referring to the analogue stereo instruments. In traditional stereo photogrammetry, the position of a point object is determined by the resection of two rays. In the analogue stereo instruments, this is physically realized by the two rods. In extension to this, the parameters of a straight line object can be described as the resection of two planes (Figure 1) and a circular arc can be described as the resection of two cones.

![Figure 1. Line Object as the Resection between Two Planes.](image)

This analogue description has the advantage that it clearly illustrates a geometric restriction in this approach. If the
planes, which are to be resected, are parallel, no unique solution exists. The equation system in the least squares adjustment is singular. This situation occurs for straight lines parallel to the stereo base. To avoid this, a large overlap between adjacent strips is recommended, allowing stereo bases to be constructed across the strips. But due to the large least squares formulation of the problem, the operator at the digitizing table does not have to worry about any stereo bases at all.

4. ACCURACY TESTS

4.1 Previous Work

The accuracy of objects mapped by digital mono plotting, as described in this paper, has been investigated by Persson (1982). Here, the accuracy of point objects were investigated by two different studies. In the first study, an accurate testfield was targetted and photographed by a Hasselblad MK-70 camera. The flying height was 220 meters, resulting in a negative scale of 1:3600. The images were enlarged 7.5 times and digitized using an Altek table. The standard error in planimetry was 16 mm, which corresponds to 4 microns in the negative scale. The standard error in height was 76 mm, which corresponds to 21 microns, expressed in the negative scale.

In the second test reported by Persson (1982), an urban area was photographed from an altitude of 330 meters. Also in this case, a Hasselblad MK-70 was used, resulting in a negative scale of 1:5500. The ground control was digitized from a map of poor quality (intentionally) and the objects to be mapped consisted of targetted as well as untargetted points. The standard error in planimetry of the targetted points was 72 mm, which corresponds to 13 microns in the negative scale. For untargetted points, the corresponding standard error was 158 mm, which corresponds to 25 microns in the negative scale. How large part of the standard error that depended on the poor quality of the ground control being used was not studied.

One conclusion drawn from the studies by Persson (1982), is that the method of digitizing enlarged photographs seems to be accurate enough for many large scale applications, such as map revision. But the studies are too limited and additional studies are needed. In the remaining part of this section, two such studies will be described. In the first investigation, the correction of geometric distortion is studied. The second study is a more general accuracy study, where a testfield has been photographed and evaluated.

4.2 Correction of Image Deformation.

Due to the enlarging process, the images to be digitized are geometrically distorted. The object of this investigation was to study the relations between accuracy, enlargement factor, type of enlarger and mathematical method for the correction of image distortion. For this purpose, a grid of high geometric quality was used. 25 of the grid points were
used as fiducials, while 16 grid points served as check points. The locations of the fiducial marks were chosen in such a way that they corresponded to the locations of the fiducials in the Hasselblad MK-70 imageries (Figure 2).

![Grid for Evaluating the Corrections for Image deformation. Fiducials marked by circles, check points marked by crosses.](image)

Two different enlargers were used this study. The first one was an ordinary enlarger (Durst), while the second was an enlarger of high quality (Falköping). The Falköping enlarger is not common, but its use by a large reprographic consultant here in Sweden, which justified its being tested.

The methods used for the correction of the geometric distortion are affine transformation using four fiducials, polynomial interpolation by a third degree polynomial and bilinear interpolation between adjacent fiducial marks. For each combination of enlarger and enlargement factor, four different enlargements were obtained. The 24 enlarged images were then digitized using a Bendix table. The result of the study is shown in Table 1.

**Table 1.** Root Mean Square of Differences in Check Points. Microns in negative scale.

<table>
<thead>
<tr>
<th>Enlarg. equip.</th>
<th>Enlarg. factor</th>
<th>Affine transform</th>
<th>Polynom interp</th>
<th>Bilinear interp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durst</td>
<td>5</td>
<td>18</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>15</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>41</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Falk.</td>
<td>5</td>
<td>15</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>
The affine transformation is not able to correct perspective deformation, which may be caused by non parallel image planes in the enlargement process. This may explain the poor result of the affine transformation when enlarging 10 times using the Durst equipment. A perspective transformation on the four fiducials in the corners might give better results.

Otherwise, the differences between the accuracy obtained by polynomial interpolation and bilinear interpolation between adjacent fiducial marks is small. Due to the simpler computational algorithms for the bilinear interpolation, this algorithm for the correction of image deformation is chosen for use in the future.

The conclusions that can be drawn from this test are the following.

- Bilinear interpolation between adjacent fiducial marks is a simple method for the correction of the geometric image deformation. It is also a method which gives good result.

- When using an enlarger of high quality, a small improvement in the geometric accuracy can be observed, especially when the enlargement factor is increased.

- When enlarging the images by a factor of 10, a standard error as low as 7 microns may be achieved when using a digitizing table for image measurements. This standard error is of the same magnitude as the corresponding accuracy obtained using traditional stereo instruments. The instrument (digitizing table) therefore seems accurate enough for many large scale applications.

4.3 Accuracy of Line Objects.

The previous tests reported by Persson (1982) were restricted in the sense that only point features were investigated. To study the accuracy of line objects measured in mono mode, an accurate test field was used. This was created by plotting a map database using a CALCOMP drum plotter. The co-ordinates of the stored data base then served as ground control in the test.

The map was photographed in two strips using a Hasselblad MK-70 camera. Each strip consisted of five photographs. The overlap within the strip was 50%, while the overlap between the strips was 100% (convergent photography). The scale of the negatives was about 1:4000 compared to the ground truth co-ordinates (Figure 3).
Figure 3. Acquiring Photographs for the Accuracy Test of Digital Mono Plotting.

The photographs were enlarged 10 times by a Falcköping enlarger and then digitized using a Bendix table. The objects on the image were of very good contrast. This means that when evaluating the results, the objects should be considered as targetted (well defined) objects.

In this method, the positions of the line objects are represented by a base point and a direction. To create a map data base, the lines are intersected and the intersection points are stored in the base. These co-ordinates are then compared with the ground truth co-ordinates as defined by the original data base. The standard errors, as estimated by the root mean square of the co-ordinate differences were 25 microns in planimetry and 30 microns in height. For an image scale of 1:4,000, this corresponds to 0.1 meters in planimetry and 0.12 meters in height.

5. DISCUSSION

The study reported in this paper is limited to fundamental accuracy questions. When introducing digital mono plotting
in mapping organisations, several other questions should be considered, such as cost, the need for education of mono operators, interpretation questions and hardware and software needs. These considerations may be more important if the organisation, as in the case of the major part of the Swedish municipalities, lacks photogrammetric experience.

Nevertheless, a rough estimation of the cost of using digital mono plotting for map revision, indicates that the method seems to be very favourable, when compared with traditional digital stereo plotting or geodetic field surveys. Especially if existing map features can be used as ground control, the benefits of digital mono plotting will be pronounced.

The approach for map revision as presented in this paper is also an attempt to make photogrammetry better known to non-specialists. There is certainly a risk that this will decrease the quality of the result, but it might on the other hand also encourage an increasing use of photogrammetric methods.

It is also well known for most photogrammetrists that the stereo viewing in itself, increases the possibility of an accurate interpretation of the images. By using only mono viewing, the accuracy of the interpretation will probably be reduced. Depending on the objects to be classified and measured, the need for stereo viewing varies. Further studies of the accuracy of photo interpretation when using mono viewing are to be performed.

When introducing digital mono plotting in a mapping organisation, there are of course several hardware and software requirements that should be fulfilled. At the Department of Photogrammetry, KTH, Stockholm, a computer program for digital mono plotting is currently being developed. The program is named CYCLOP and is run on IBM PC computers. The first version will be tested in a map revision project later this autumn (1986).

The method described in this paper is also well suited to semi-automatic methods based on digital image processing (DIP). Stereo workstations for DIP are rather uncommon, in contrast to mono workstations. A semi-automatic system can then be designed in such a way that the digital images are interpreted by an operator. When placing the cursor at an object, a feature code is entered and automatic line following algorithms follow the edge of the object. An image matching algorithm for matching features in adjacent images need not necessarily be based on pointwise matching, as is often the case today. It can as well be based on objectwise matching.

6. CONCLUSIONS

In this paper, the accuracy of digital mono plotting has been studied. It is assumed to be used for the revision of large scale base maps. For some types of features, such as real estate borders and buildings, the accuracy demand is
rather high, while the demand is less for other types of features, such as streets, paths, fences etc. Especially in the latter case, digital mono plotting seems to fulfill the accuracy requirements and may reduce the costs for data acquisition considerably. The current problems in the revision of large scale base maps are also focussed on this latter kind of feature.

7. ACKNOWLEDGEMENT

This work has been financially supported by The Swedish Council for Building Research (BFR), contract number 830247-0. I would also like to thank Tiina Kilpeläinen, Ulla Nyström and Björn Persson, for their contributions to the content of this paper.

8. REFERENCES


