THE USE OF LINEAR FEATURES AS REFERENCE DATUM IN DIGITAL MAP REVISION

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Abstract

In this paper we shall present the idea of connecting the concept of linear features to a digital map revision process. The purpose is to simplify map revision with digital or digitized images, by using linear features derived from GIS as reference datum instead of pointwise control, and by digital mapping. Some simulation results will be given to show the capability of linear features in close-range and aerial photogrammetric tasks.

Key words: Map Revision, Linear Features, Geoinformation System

0. INTRODUCTION

Traditionally, the main part of the time spent in mapping processes has been required for preliminary tasks i.e. field surveys. For minor mapping processes, e.g. map revision purposes, very careful and precise design have been required in order to achieve sufficient accuracy. Usually, standardized methods have been used concerning the number of control points, their distribution and the size of overlap. This kind of procedure obviously guaranties the quality of mapping, but the relation between the amount of time and money spent on the process compared with the size of the mapping area can be poor specially in the case of map revision projects. For this reason a new, more flexible method could be applied and, still, fulfil the requirements of accuracy.

An alternative approach to accomplish a project is to use old, existing objects of the area in question as the control datum. In very many cases we have some a priori knowledge of the area. Very often surveys have been done in earlier times and their results have been stored and can be found. In an ideal case the information is already in a numerical form, e.g. in a GIS database. The objects in question could be roads, their edges, or blocks of buildings. It is required that the data is stored with 3-dimensional coordinates. At the moment, this kind of data is, unfortunately, seldom available. Also, some information about accuracy is desirable. Nowadays 3-D LIS/GIS implementations are rapidly expanding and already some companies and institutions are providing such databases.

In order to replace control points with objects, we must use methods of feature based photogrammetry. The basic idea is to determine some linear features in a parametric form from the original image observations on several photographs. Vice versa, resection can be performed based on a 3-dimensional model of some features to determine the position and orientation of the cameras. Intuitively it is true, it is hard to achieve the same accuracy on control features as by measuring geodetic points. On the other hand, a linear feature in parametric form consists of data in a very compact form. We claim that the increased number of control data substitutes the requirement of their accuracy. Linear features are more stable and their parametric form stabilizes the solution of exterior orientation, because the image observations of one feature are more dependent on each other.

1. USE OF LINEAR FEATURES

1.1 Parametric formulation of linear features

As mentioned, parametric form of linear features is very compact and consist of an enormous amount of information about the object curve. In this sense, the position of features and its orientation on photographs have effect on the results. Power of these methods is shown later with examples.

For photogrammetric applications the most common types of linear features are space line, circle, ellipse, parabola, hyperbola, and parametric 3D spline. They all include different number of parameters in a parametric form of presentation. Also, in order to determine object features implicitly, every type of feature has at least one constraint specifying the parametric formula. Every different type of linear feature has a unique formulation of a photogrammetric relation.

In this chapter we shall give a short overview of the presentation of linear features and their photogrammetric treatment as by David Mulawa /Mula89/, /MuMi88/.

Let us think about some three dimensional curve. Trace of the curve consists certain set of points P_i.

$$F_i\text{: } \{ P_i \} \quad (1)$$

In the parametric formulation we can find a common set of parameters u_i on which all points of curve are dependent. The general formulation of parametric presentation can be given as,

$$P_i = P(u_i) = \begin{bmatrix} x(u_i) \\ y(u_i) \\ z(u_i) \end{bmatrix} \quad (2)$$

u_i : set of parameters connected with feature specified by index i

In the case of space line, the set of parameters consists of six elements: $\{C_x, C_y, C_z, \beta_x, \beta_y, \beta_z\}$. These parameters are denoting the elements of two vectors. The first vector is so-called **reference** point and can be any point on the line. The second one is pointing the **direction** of the line in space. It is true that any two different points of the line specify a line implicitly in a three dimensional space. The lack of implicity in this kind of presentations means we can form an infinite number of presentation for the same line. To discard such a multiple determination, we have to agree on some regulations for the selection of the reference point and the direction vector, which can be the nearest point of the line from the origin. In other words, the vectors $\vec{C}$ and $\vec{\beta}$ are perpendicular to each other. To define the direction vector as unique it can be supposed to be a normal vector.

$$\begin{cases} \vec{C} \cdot \vec{\beta} = 0 \\ \vec{\beta} \cdot \vec{\beta} = 1 \end{cases} \quad (3)$$

This kind of formulation determines the line implicitly, but quite often an additional parameter t is used in the presentation specifying a certain point on the line. This kind of specification is utilized in the photogrammetric treatment of lines based on the collinearity condition. The parametric presentation of a line is depicted in Figure (1).

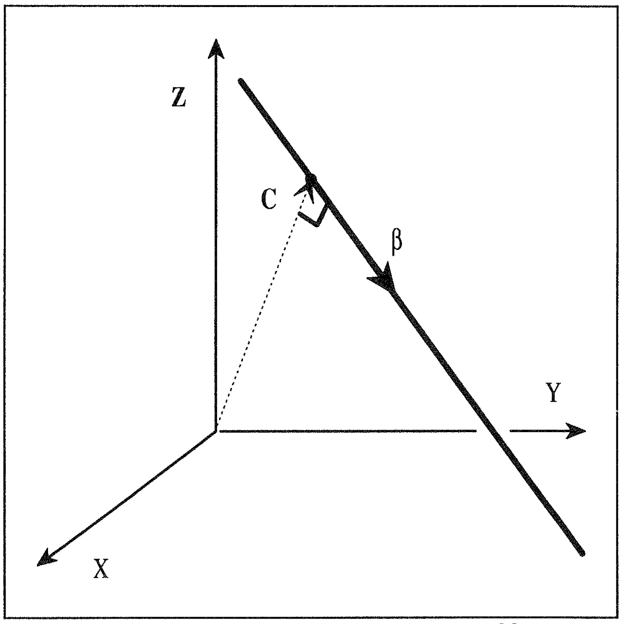

Figure 1 Parametric presentation of line.

The formulations of other feature types are based on same kind of approach. Vector algebra is playing a very important role in these formulations as in the equations presenting the photogrammetric relations.

1.2 Photogrammetric treatment of linear features

The intersection of linear features from several images is regarded as three dimensional form fitting, which requires the dependencies of image observations and parameters of the feature to be solved. With resection we have the same requirement. The photogrammetric relations can be divided into two categories: parametric and implicit relations. The first uses an additional parameter pointing position of the point along feature. The second only presents the implicit relation between the observations and the parameter set.

In the case of a space line, the parametric relation is built on the collinearity condition. This relation can be written by including the parametric formulation of the object feature point in an equation,

$$x = -c\,\frac{m_{11}(X(t)-X_0)+m_{12}(Y(t)-Y_0)+m_{13}(Z(t)-Z_0)}{m_{31}(X(t)-X_0)+m_{32}(Y(t)-Y_0)+m_{33}(Z(t)-Z_0)} \quad (4)$$

$$y = -c\,\frac{m_{21}(X(t)-X_0)+m_{22}(Y(t)-Y_0)+m_{23}(Z(t)-Z_0)}{m_{31}(X(t)-X_0)+m_{32}(Y(t)-Y_0)+m_{33}(Z(t)-Z_0)}$$

or by using the collinearity equation consisting of object point coordinates and constraining them to be dependent on the parameter of the curve t.

$$x = -c \frac{m_{11}(X-X_0)+m_{12}(Y-Y_0)+m_{13}(Z-Z_0)}{m_{31}(X-X_0)+m_{32}(Y-Y_0)+m_{33}(Z-Z_0)}$$

$$y = -c \frac{m_{21}(X-X_0)+m_{22}(Y-Y_0)+m_{23}(Z-Z_0)}{m_{31}(X-X_0)+m_{32}(Y-Y_0)+m_{33}(Z-Z_0)} \quad \textbf{(5)}$$

$$\begin{cases} X = X(t) \\ Y = Y(t) \\ Z = Z(t) \end{cases} \quad \textbf{(6)}$$

The photogrammetric relation is illustrated in Figure (2).

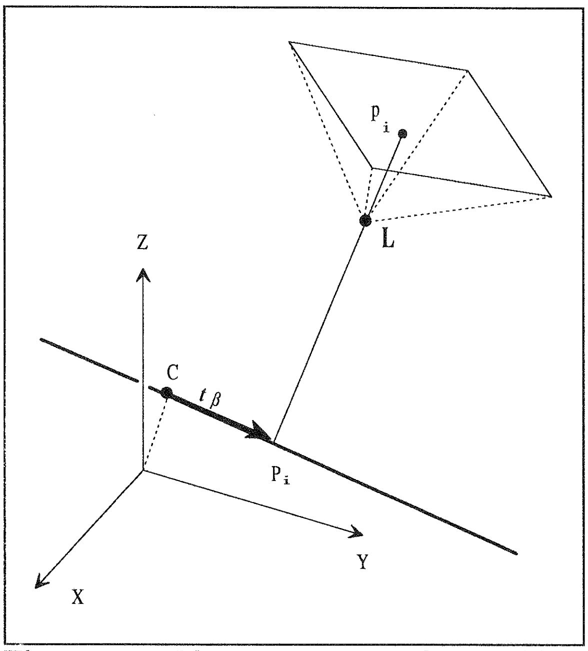

Figure 2 Photogrammetric relation of line established by parametric equation.

Another way to establish the photogrammetric relation is to form the implicit equation between the observation point and object parameters. This kind of approach includes both x- and y-observations in the same equation. The formulation tells us only the observation point is the image of one of the points of the whole set of feature points. There is no parameter expressing the position of the point. It gives us more redundancy in the determination with same size of observation sets.

With space lines an implicit equation is expressed by three vectors. The condition to be satisfied by these vectors is that they are coplanar, i.e. laying on the same plane. Vectors involved are the direction vector $\bar{\beta}$, the vector between the centre point of the line and the projection centre (L-C), and the image ray ρ. The relation can be expressed,

$$|\bar{\rho}\,\bar{\beta}\,(\bar{C} - \bar{L})| = 0 \text{ ,where}$$

$\bar{\rho}$ *: direction vector of image ray in space*
$\bar{\beta}$ *: direction vector of the line*
$\bar{C}$ *: centre point of the line*
$\bar{L}$ *: projection centre of the camera*

(7)

The photogrammetric relation is depicted in Figure(3).

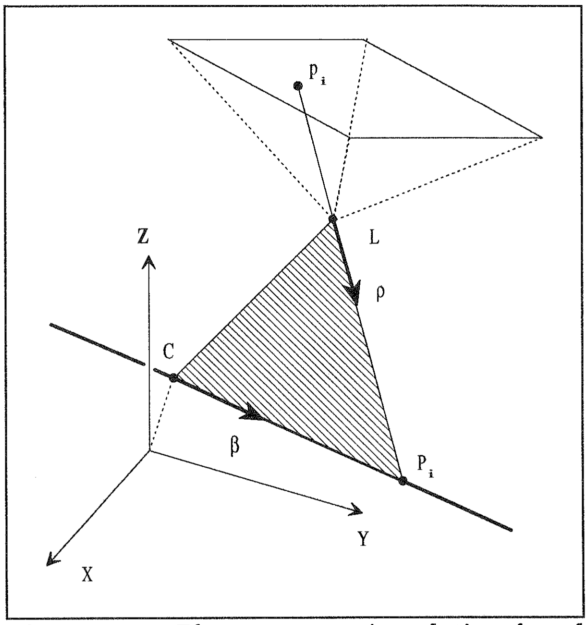

Figure 3 Photogrammetric relation based on the coplanarity condition.

In this chapter we have dealt only with line feature type. For the other types of features same kind of approach can be used. More information about the construction of photogrammetric equations as well as about the procedure of estimation of linear features can be found in the works of David Mulawa and Edward M. Mikhail /MuMi88/.

2. PROCEDURE OF A MAP REVISION PROCESS

Nowadays mapping processes in urban areas are accomplished in the same way as any other mapping process. Aerial photograph blocks have been designed with standard parameters; block consisting of at least two flight strips with sidelap of 20%-60% and endlap of 60%-80%. Also number of control points and their distribution is determined according to standards. This kind of approach requires quite a lot of work and time especially in the case of map revision. The most time consuming phases are the field surveys and the targeting of the ground points (Figure 4.).

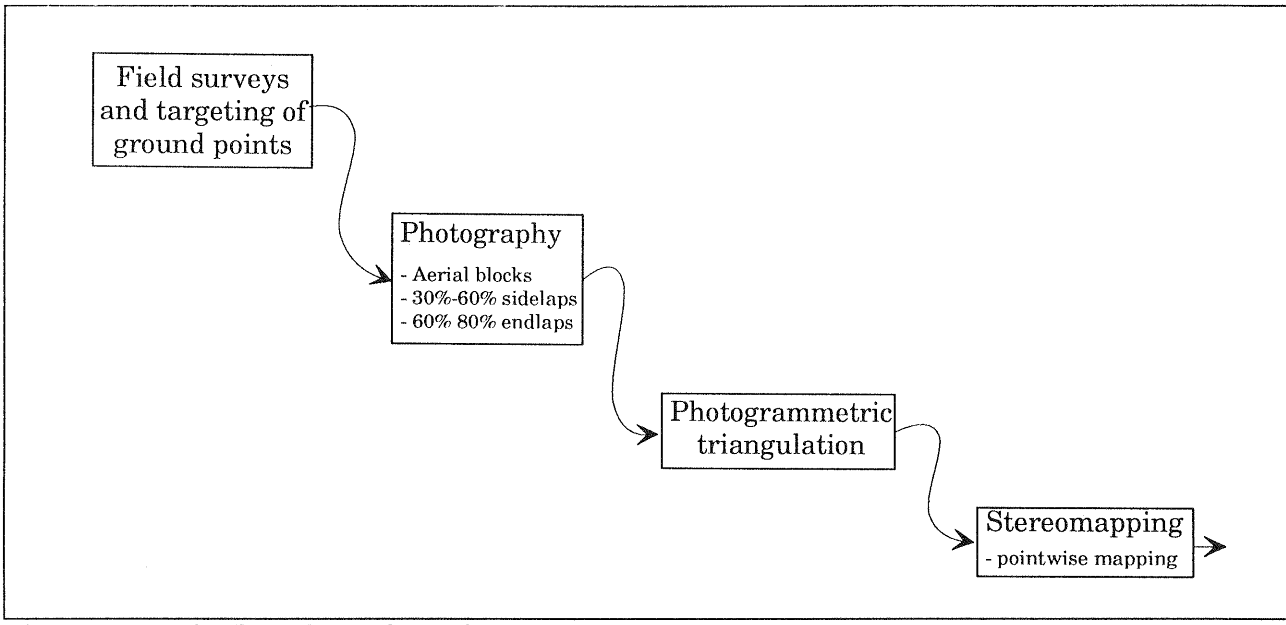

Figure 4 The flow of a traditional mapping process.

In our procedure the standard methods of pointwise photogrammetry are not necessary. By using linear features we can deal with different types of images which is not typical with traditional methods. Also the use of images produced by different kind of sensors is possible. Actually, the problem with different exterior orientations of the satellite image rows, censored by row detectors, can be handled with the use of linear features.

Because we are not using targeted ground points as the control datum but the existing features of area in question, geodetic measurements on field are not needed. This approach depends on the assumption of having a priori knowledge of the mapping area. The numerical information of object coordinates can be stored in any kind of database. The only requirement is that coordinates are stored with some logic. In our application we are using a GIS/LIS-system as a storage device. The system we are using, ARC/INFO, does not support 3D objects, so the third coordinate is handled as an attribute information. For data acquisition we are using routines provided by the system. Perhaps the severest drawback in this method is that information about the accuracy of object coordinates is rarely available.

When all suitable object curves have been found, their images on photographs have to be found. The criteria of suitability is not very implicit. It can be based on the criteria of accuracy as well as the position and orientation of curves respect to the area of the photograph. Anyhow, it will, at least partly, be dealt in a heuristic manner. From 3D point coordinates of curves the parameters of linear features will be constructed. At this stage some estimates for the accuracy of parameters can be received. As we know the image of a linear feature is also a curve in a two dimensional photograph. In some case, image of a line could be a point, but that is very rare. With analog photographs observations can be done in the same way as it has been done before with analytical plotters. To find the curves from digital photographs we can use two different approaches. First, we can try to fit some 2D splines into the image and estimate visually when a curve fits in with a trace of the feature. In many graphic libraries there are many different drawing types of curves available. Another approach is to imply edge detection methods to find the location of edgels according to the grey level values and link them to a whole curve. The latter approach is more accurate, but because it is based on automatic algorithms some robust estimation techniques should be implied. To develop this kind of system will probably take many years.

The next problem is to find the correspondence between the object features and their images on photographs. A manual procedure with an operator pointing out the correct images of the features on images is perhaps most reliable at the moment. For this purpose several LIS/GIS-systems provide some kind of projective monitoring routines based on initial values of the exterior orientation. Automatic algorithms, too, have been developed for same tasks. Those algorithms are mainly designed for traditional, pointwise methods. Finding the "suitable" features and their images on photographs leads to the determination of exterior orientation of photographs in question. Performing a photogrammetric triangulation is possible as well, but as it is based on the idea of block adjustment, it may be too rigid in small map revision projects.

As the final goal is to produce a map or to import data for some planning projects, we have to find the difference between the existing data in the database and the new data determined by the intersections performed on several photographs. For this we need to find the corresponding images of each feature on different photographs. The same requirement is valid when constructing stereo models for mapping in stereo mode. Algorithms for this task have been widely designed, but only for finding homogenous points on several photographs, and we need to use robust methods in same sense as in edge detection.

At first, our aim is to employ a manual approach to overcome the problems mentioned earlier. In second stage automatic methods will be implemented, if manual methods prove the capability of this procedure in mapping projects, as we believe. The flow of the process is described in Figure 5.

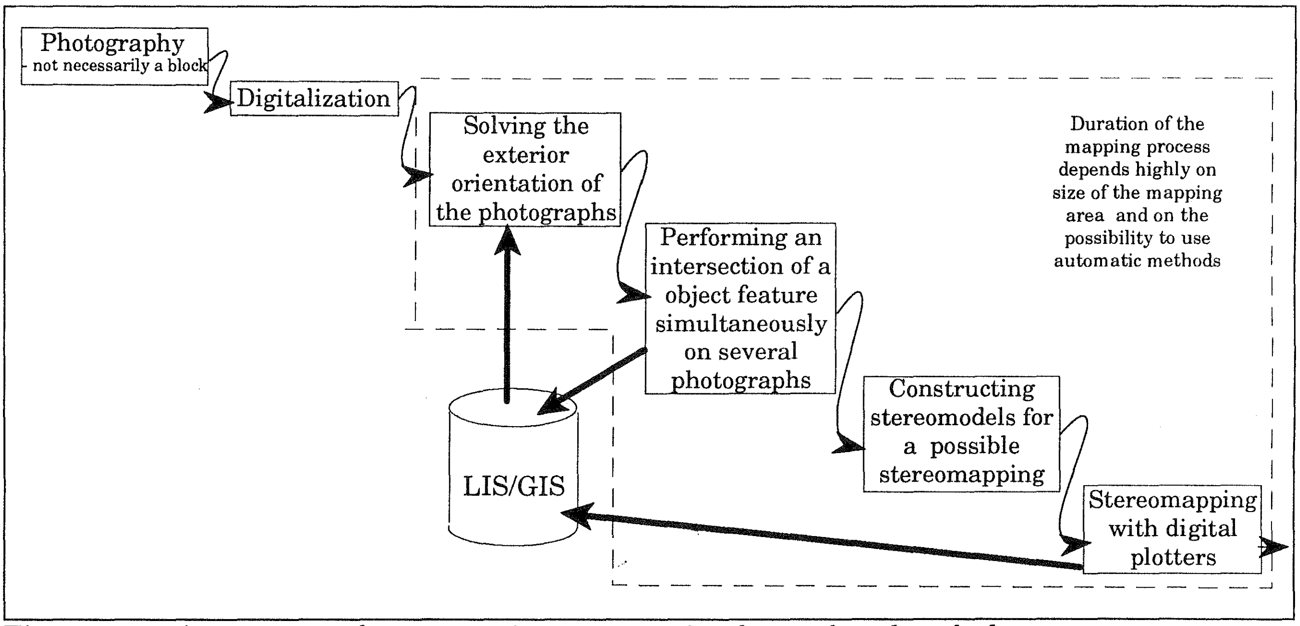

Figure 5 A new approach on a mapping process using feature based methods.

3. CAPABILITY OF LINEAR FEATURES

At the Helsinki University of Technology some tests have been made to find the capability of the use of linear features in photogrammetric tasks. All tests have been accomplished with simulated data. The means of the accuracy are theoretical and show only the magnitude. Tests have been done mainly for space lines, circles and parametric splines.

The capability of features in case of intersection has been the top interest. Some research about the exterior orientation with linear features have also been done with few feature types. Variables in the tests have been the number of points included in computation, position of the feature on a photograph, and the orientation respect to the datum.

In case of close-range photogrammetry and mapping simulated tests with line features have been accomplished. In the mapping example only one line feature was determined. In the test photographs were added into computation one by one and at the same time the number of observations was also increasing. The block of aerial photography had three flight strips consisting of three images each. So, the maximum number of images was nine and the maximum number of observation points obtained was 63; 11 points of the photographs in middle flight strip and 5 of the other two strips.

The results are presented in average standard, error ellipsoids. The ellipsoids are supposed to construct a probability tube around the trace of the curve. Additionally, all figures are scaled into the image space. This means the results are independent on the circumstances of the photography.

To get the numbers of accuracy of a specific configuration, you have to multiply the results by a scaling factor $s=(h/c)\sigma$, where h denotes approximate object distance from the camera and c is the camera constant. σ is the estimated noise level on images. The results of the test previously mentioned are depicted in Table 1.

Photos	2	3	4	5	6	7	8	9
Axis 1	1.006	0.513	0.513	0.513	0.475	0.438	0.402	0.368
Axis 2	0.296	0.254	0.237	0.221	0.209	0.201	0.190	0.182

Table 1 The accuracy of line respect to number of photos included. /Heik92/

Same kind of tests were employed for circles. In this case we tried to find out if the accuracy gets better with an increased number of observations. Another interesting factor was to see, how the size and the shape of the average ellipse changed when the object circle was tilted. The results are presented in Figures 6 and 7.

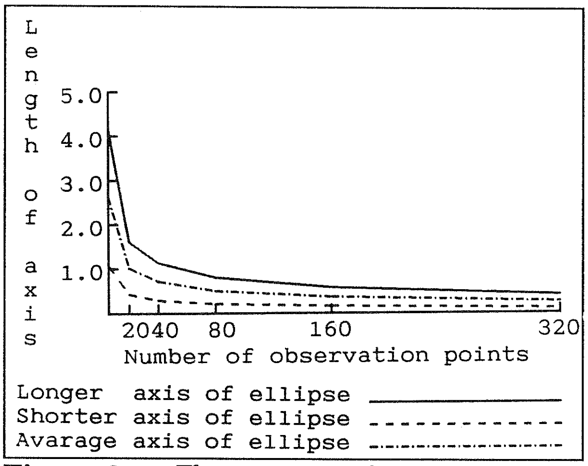

Figure 6 The accuracy of intersection respect to the number of observations. Circle feature. /Heik92/

Results are quite promising, but we have to keep in mind no errors were assumed in the orientation parameters of the photographs.

To get some knowledge of accuracy of the exterior orientation, some tests were designed. The determination of exterior orientation parameters was accomplished both with pointwise and feature based methods for comparison. Features used were space lines and 3D-splines.

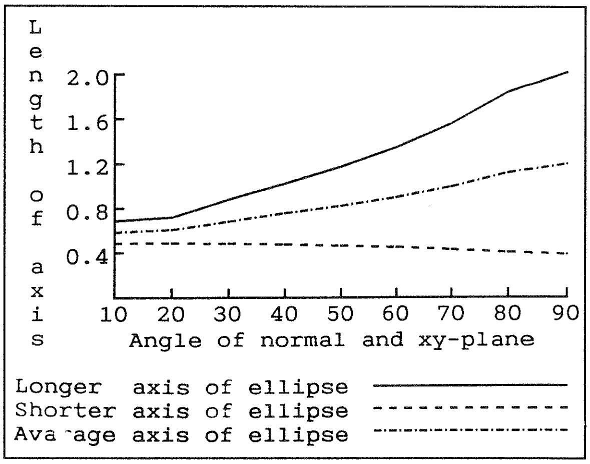

Figure 7 The accuracy of intersection respect to the orientation of the object feature. Circle feature. /Heik92/

In the case of lines, the minimum number of object lines needed is three. Object lines should not be parallel and all three lines should not intersect at the same point for the exterior orientation to be implicit.

Sari Metsämäki studied the use of linear features in exterior orientation /Mets91/. The observations were done on the photographs as shown in Figure (8). The results of the estimation are given in Table (2). The reason, why there were 24 observations in the feature based method and 8 (x and y are considered as one observation each) in pointwise, is the use of collinearity equation which produces one additional parameter per observed point. In this way redundancy was the same in both cases. The precision of the determination is presented with weight coefficients of the orientation parameters.

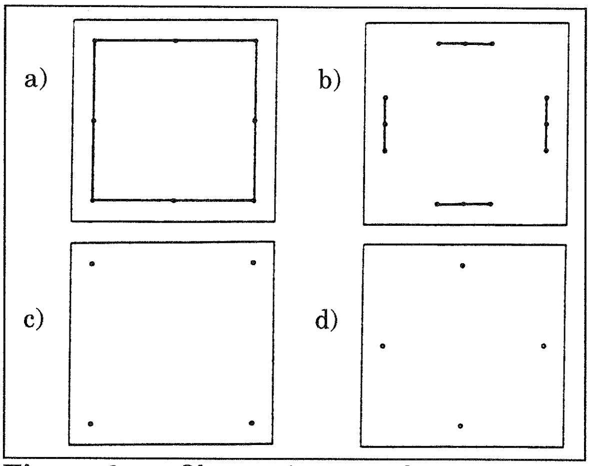

Figure 8 Observations made in feature based method **a)**, **b)** and in point wise method **c)**, **d)**. /Mets91/

	Feature based a	b		Pointwise method c	d	
Xo	6.36	18.69	Δ=12.33	6.43	10.91	Δ= 4.48
Yo	6.36	18.69	Δ=12.33	6.43	10.91	Δ= 4.48
Zo	1.58	1.58	Δ= 0.00	1.94	2.74	Δ= 0.80
ω	0.58	1.74	Δ= 1.16	0.58	1.16	Δ= 0.58
φ	0.58	1.74	Δ= 1.16	0.58	1.16	Δ= 0.58
κ	0.25	0.74	Δ= 0.49	0.25	0.35	Δ= 0.10

Table 2 Weight coefficients of exterior orientation parameters. Datum used in the determination; four feature lines and ground points. /Mets91/

From Table (2) it can be seen that, when the observations are made in a very narrow interval, same accuracy cannot be achieved with feature based methods as with pointwise methods. With a rational selection of observations there are no difficulties to determine the parameters as accurately as with pointwise methods. We have to remember that by using feature based methods, we are able to make more observations along the line much more easily than by measuring more ground points in pointwise methods. Obviously, the increased number of observations improve the precision of estimation.

Same kind of experiment was accomplished with splines. Because the photogrammetric treatment was based on the collinearity condition, once again there is a different number of observations. In the feature based method 32 and in pointwise method 10 points were observed. The distribution of points is illustrated in Figure (9).

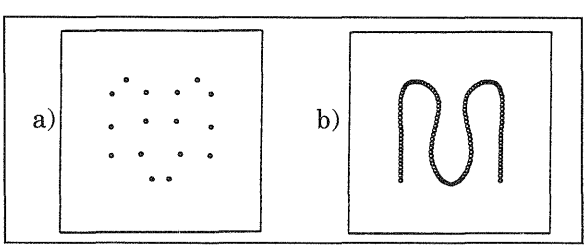

Figure 9 The distribution of observations in a pointwise approach **a)** and in a feature based method along a spline **b)**. /Mets91/

	Feature based	Pointwise method
Xo	7.84	9.13
Yo	9.32	9.16
Zo	1.52	2.13
ω	1.29	1.35
φ	1.15	1.34
κ	0.38	0.34

Table 3 Weight coefficients of exterior orientation parameters. Datum used in the determination; spline feature and ground points. /Mets91/

In Table (3) the precision of estimation is given in a same manner as previously.

4. CONCLUSIONS

In the previous presentation we have shown that feature based methods are competetive with the pointwise approach. It can be stated that hardly any object line or curve could measured with the same precision as the corresponding accuracy of ground points. But the main thing in feature based methods is you can make much more observations along a linear feature and thus making the determination of exterior orientation at least as accurate as with the pointwise procedure. In the case of intersection, the accuracy of pointwise methods was easily achieved.

Assuming that with real, practical projects we can get same results, feature based methods will be a real, considerable alternative for the standardisized procedure of map revision. Even with the semiautomatic approach, savings of time and money with be noticeable and speak on behalf of the use of this new method. We are convinced that in few years numerical databases, with numbers of accuracy, will be quite common providing thus good potentials to imply feature based methods in practical map production.

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