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DETERMINATION OF EXTERIOR ORIENTATION USING LINEAR FEATURES FROM VECTOR MAPS

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Abstract

This paper presents a procedure for the determination of the exterior orientation (EO) of images using existing digital vector maps. The most important characteristic is that there is no need for signalised ground control points (GCPs), because the EO is carried out solely using ground control lines (GCLs) acquired from the geographical information system (GIS). Although the proposed EO procedure could be fully automated, a small amount of operator guidance is needed in the adjustment of the initial EO, which should be moderately accurate prior to automating the EO procedure. However, adjusting the initial EO parameters is fairly easy, because the projected locations of the map vectors on the image are updated in real time on the computer monitor. Ultimately, the final EO is determined by using an automatic method that uses a local line scanning technique that attempts to locate the linear features from the image. The final EO is calculated using the line photogrammetry method. The EO procedure was implemented as software running in a Microsoft Windows environment and, although the software is able to process only one image at a time, it provides a way to determine the EO that is both reliable and rapid. The test results showed that the accuracy achieved depends on the positional accuracy of the linear features used. Therefore, 2D coordinate shifts in the vector maps will be directly passed to the EO parameters without other control.

KEYWORDS: exterior orientation, line photogrammetry, linear features, vector map

INTRODUCTION

IN ORDER TO MEASURE object space coordinates from any remote sensing images, the exterior orientation (EO) of the sensor at the time of image acquisition is needed. Grussenmeyer and Al Khalil (2002) defined the EO of the image as referring to the position and orientation of the sensor related to the object space coordinate system. In the case of a perspective camera, the EO is determined by the position of the perspective centre (X_0, Y_0 and Z_0) and three rotation angles (ω, ϕ and κ). However, any other sensor model such as direct linear, affine, projective or rational function transformation would also be applicable, and occasionally, the term "image registration" has been used as a synonym for the EO. In any event, the objective of the EO is to overlay images taken at different times, from different perspectives and with different sensors in order to carry out, for example, change

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detection, mapping, map updating, image mosaicking or stereoplotting (Zitová and Flusser, 2003).

In principle, control features used in the EO determination can be collected by means of either area- or feature-based methods (Zitová and Flusser, 2003). Area-based methods use raster type geographical information system (GIS) data, in which matching is based on image intensities (grey values) such as image correlation. Area-based methods are typically suitable for images acquired with similar sensors, or otherwise it might be impossible to find the same image window from both reference and sensed image automatically (Zitová and Flusser, 2003). On the other hand, feature-based methods use GIS vector data types, which are points, lines or polygons. A typical example of the point-based method is the photogrammetric aerial triangulation, where few signalised ground control points (GCPs) are required to tie a block of images to the ground coordinate system. The problem in the automation of aerial triangulation is absolute orientation (Dowman, 1998). In current commercial software packages, absolute orientation is typically carried out by manually digitising the signalised GCPs from the aerial images. It is also possible that signalised GCPs do not exist in sensed images; the required control could be obtained from existing maps or ortho-images instead. However, if the vector map consists of lines, it might be impossible to find GCPs on maps that can be also located on the imagery. There has been quite a lot of interest in EO procedures that exploit vector maps. For example, Dare and Dowman (2001) proposed a three-step method, where, firstly, the initial EO was determined with a few points; secondly, the EO was enhanced using regions (patch matching); and thirdly, the final accurate registration was made by using lines. Schickler (1992) used 3D wire-frame models of buildings in the EO, where 2D projection of the building model was located from the sensed image leading to a control point set, which was used in the determination of the EO. Even though both methods used lines in the image registration, the full value of linear features was not exploited, because edge pixels and matched 2D buildings were treated as tie points (Schickler, 1992; Dare and Dowman, 2001). It is evident that linear features are feasible in the EO and they have a lot of potential in the automation of the EO procedure. Schenk (2004) presented five reasons for linear features being preferable to point features: (1) automatically extracted points do not contain semantic information; (2) there are more linear than point features in aerial images, at least in urban and agricultural areas; (3) existing vector maps are rich in linear features; (4) the matching of linear features is more robust and easier than for point features; and (5) linear features form the fundamental basis for the automation of the photogrammetric process.

In order to gain the full benefit from using linear features, a different mathematical model is needed from the one used in point-based EO. One of the original ideas for the use of linear features in photogrammetry was presented by Masry (1981). Later, Mulawa and Mikhail (1988) described the photogrammetric treatment of linear features in space resection. Similar methods were proposed by Tommaselli and Tozzi (1996), Habib and Kelley (2001), Habib et al. (2003), Habib and Alruzouq (2004) and Schenk (2004) to name but a few. Similar ideas have also been presented in the field of computer vision, for example, by Liu and Huang (1988). In line photogrammetry where a perspective frame camera is used, there are fundamentally two approaches to using linear features: the coplanarity and collinearity models (Schenk, 2004). The coplanarity model requires all three of the directional vectors defining the ground control line (GCL), the vector from any point of the GCL in the image to the perspective centre and the vector from a fixed point in the GCL to the perspective centre to lie in one plane (Mulawa and Mikhail, 1988). At the least, three non-parallel GCLs are required to determine the EO of the image. The use of the coplanarity equation in the single image EO is explained later in this paper. Schenk (2004) also presented an alternative method, based on the collinearity model, where any point of the GCL on the image, the same point in the GCL and the perspective centre must lie on the same straight line. In Schenk's formulation three GCLs are also needed in the determination of the EO. However, if straight line segments are used as control features, the coplanarity and collinearity models are comparable with each other. Although a lot of research has been carried out using linear features, they are, to the best of the authors' knowledge, still not used in commercial photogrammetric and remote sensing software packages.

The most difficult and challenging problem in the EO is how to locate control features automatically from the sensed image. In practice, control features can be located and matched either locally or globally. Obviously, the simplest way is to use a local method that attempts to locate GCLs one by one from small image windows, where the GCLs are presumably located. However, relatively accurate initial EO values are required. Otherwise matching would probably be unsuccessful. On the other hand, a global matching method would, firstly, extract all candidate linear features from the sensed image and, secondly, attempt to find matching lines from the vector map. Horaud and Skordas (1989) used a global graph matching method to register two images to each other. While this method seems to cope well with indoor images, its use in the case of aerial images would be rather difficult, because of the enormous number of lines in both aerial images and maps. In general, if there were m reference features and d image features, then the number of possible pairs would be 2^{md}, but since these two data-sets are symmetrical, the complexity of the problem grows as a function of $(md)^2$ (Beveridge and Riseman, 1997). However, the complexity of global matching in the case of aerial images and existing vector maps is very high. Thus a local matching method is more favourable than a global one. Moreover, the increasing availability of direct georeferencing information (through global positioning system (GPS)/inertial navigation system (INS)) favours the use of local matching methods.

The objective of this study was to develop a method for determining the EO of images using linear features obtained from vector maps. Although the original idea was only to carry out the EO, the proposed method also provides a way to verify the accuracy of the initial EO quickly and to improve it if necessary. Although the accuracy of direct georeferencing systems continues to improve, and GPS/inertial measurement unit (IMU) performance can be upgraded significantly using error modelling and compensation techniques (Grejner-Brzezinska et al., 2005), direct georeferencing still involves extrapolation; some external control, such as the use of existing maps, would thus be advantageous.

Method

The EO method presented here is based on the linear features derived from existing vector maps. Basically, the vector map can consist of any type of linear features such as building outlines, parcel boundaries, roads or even line segments that have been automatically extracted from existing ortho-images. The process flow of the EO is presented in Fig. 1.

The process starts with a new aerial image. To begin with, initial EO parameters are needed, for example, the ones obtained from the direct georeferencing system. Otherwise the operator must provide the estimated location (X_0, Y_0 and Z_0) of the camera and its pose (ω, ϕ and κ). The rotation order of κ, ϕ and ω has been used in this case. Nevertheless, rather rough EO estimates are enough, because these parameters can be adjusted interactively at a later stage. Interior orientation can be determined by digitising fiducial marks, but it can also be read from a file since nowadays digital aerial cameras with known interior orientation are coming onto the market.

Next the vector map is read from the GIS file. These vectors can be 3D lines, but usually they are 2D lines. Thus the elevations of the endpoints of the vectors can be obtained from the digital elevation model (DEM). If a DEM is not available then a constant elevation can be set for the vector endpoints. Then vectors are projected in real time onto the image on the monitor

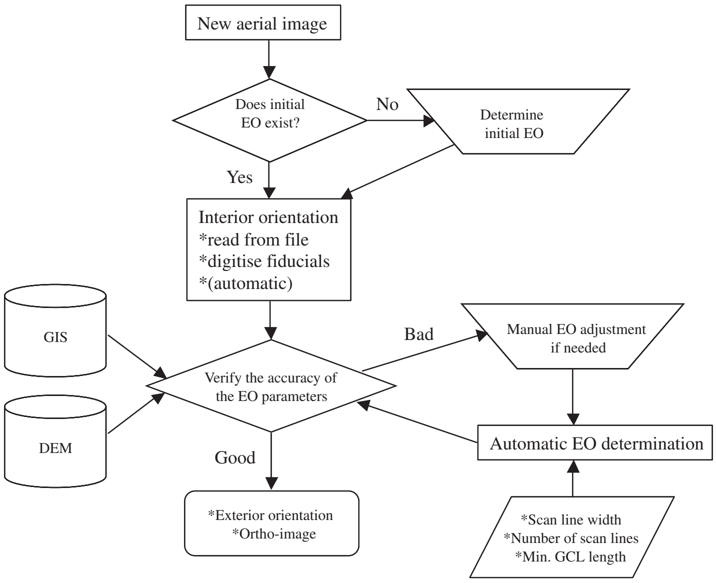

FIG. 1. Flow chart of EO procedure.

using the interior and initial EO parameters. If the initial EO is accurate then the vectors of the map will be projected correctly onto the image, and perhaps no additional refinement will be needed. However, if the initial EO is inaccurate, then map vectors are projected to erroneous locations on the image. To improve the initial EO, there are six slide switches, one for each EO parameter, which can be used to adjust the EO parameters manually. When slide switches are moved, the changed vector locations on the image will be updated in real time, and better EO parameters than the initial ones one can quite easily be found (if familiar with photogrammetry). The optimal sequence for EO is: centre part of the image is used to adjust X_0 and Y_0, image parts at "3, 6, 9 and 12 o'clock" for Z_0 and κ, and finally image corners for ω and ϕ rotations (Habib et al., 2003).

Although it might even be possible to find a seemingly accurate EO manually, the final EO should preferably be carried out using an automatic procedure, in which the goal is to locate the map vectors from the sensed image. In general, such a method would consist of two steps: (1) edge detection and (2) feature matching. In the first step, some primitive edge detector could be used (such as Sobel or Prewitt convolution masks) to extract edge pixels from the sensed image. An alternative approach for edge detection would be the Hough transform, which provides detected edges directly in the parametric form (Habib and Kelley, 2001). In the second step, which is called feature matching, the aim is to search for corresponding pairs of linear features between the edge image and the vector map. With respect to the implementation of the automatic EO method, the edge detection step is straightforward. However, the most difficult problem is the step of feature matching since the number of possible pairs of linear features could be enormous. Especially in the case of aerial images, there are typically large numbers of detected edges that do not exist in the vector map at all. Therefore, it was decided to use an approach called a scan line method, which tries to find the GCLs of the vector map locally from the aerial image. The main advantage of the scan line method is that there is no need to carry out separate edge detection prior to the feature matching because the initial EO provides the rough location of the GCL. Therefore, the difficult problem of finding corresponding features is avoided and the automatic EO process is fairly quick in practice. However, the disadvantage of the scan line method is that the EO obtained thereby could be utterly defective if the GCLs are not located within the endpoints of the scan lines.

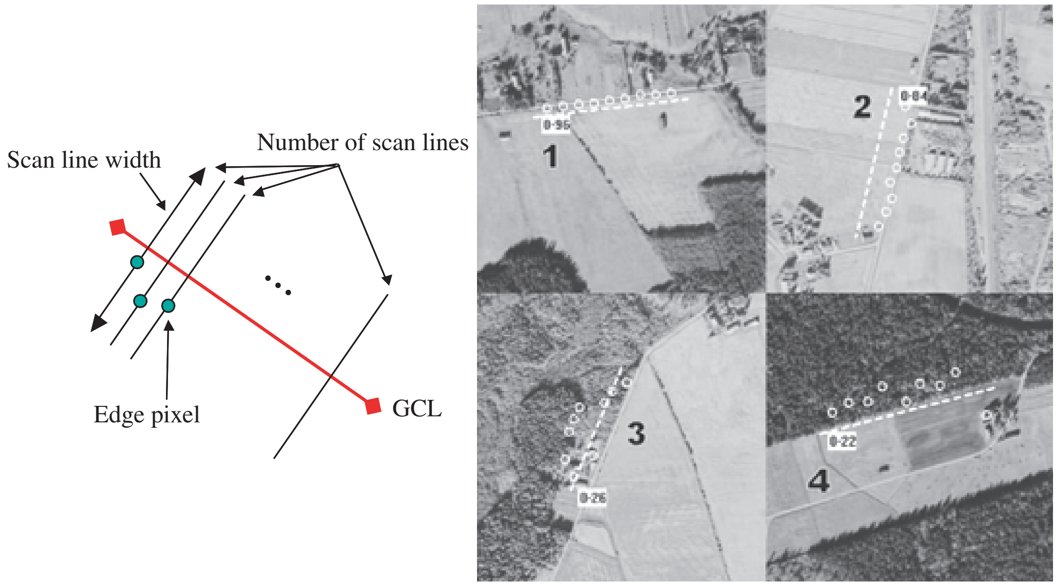

FIG. 2. Idea of local line scanning and four example cases.

Therefore, in the scan line method the initial EO needs to be relatively accurate and above all comparable to the width of the scan line used in the image processing.

The proposed scan line method is based on the 1D Canny edge detection operator, where map vectors are scanned perpendicularly on the image plane. Because edges are detected in real time, there is no need to carry out edge detection prior to the matching. In the Canny edge detection the zero-crossing point of the second derivative of the signal of the scan line is considered to be a candidate edge pixel representing the line segment in question. If more than one zero crossing is found, then the pixel with the strongest gradient is selected. Then the scan line is moved parallel along the line segment, the result being a set of candidate edge points hopefully representing the line segment in question (see Fig. 2).

There are only three input parameters for the automatic algorithm: (1) the number of scan lines per line segment; (2) the width of the scan line; and (3) the minimum length of the GCLs (in metres) that will be used in the orientation. The number of scan lines could be changed freely, but at the moment it is fixed to nine, which usually provides enough edge candidate pixels. On the other hand, the width of the scan line and minimum length of the GCL are adjustable. In a favourable situation a good result might be achieved immediately on the first try. However, the following sequence is typically needed to achieve the desired result:

(1) Check the accuracy of the current EO from the computer monitor and adjust the scan line width accordingly.
(2) Adjust the minimum length of the applied GCLs (in the beginning only the longest GCLs should be used, but finally all GCLs can be included in the processing).
(3) Start the scan line method to obtain a new EO.
(4) Check the accuracy of the new EO from the computer monitor.
(5) Repeat stages 1 to 4 until the EO is satisfactory.

The most difficult problem, especially in the case of aerial images of a natural scene, is that the scan line method might produce a large number of erroneous edge pixels, as can be seen in example cases 3 and 4 in Fig. 2. Parallel lines that are closely located are also potentially hazardous with respect to the line scanning method, but they are typically avoided when the scan line width is narrow enough. Poorly detected linear features can be avoided by

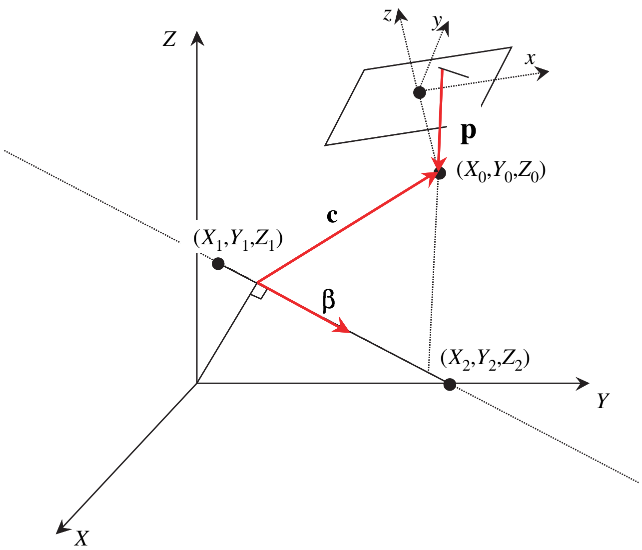

FIG. 3. Coplanarity model used in line photogrammetry.

fitting the equation of a line to the given set of candidate edge points. A goodness-of-fit value is calculated and is used as a weighting factor when the EO is calculated. The goodness-of-fit value corresponds to the distance of edge points from the fitted line (rmse normalised in the interval [0, 1] using the scan line width). Thus, the poorly detected linear features will most likely have a low impact on the determination of the EO. Basically, the power of the method presented is that in the vector maps there are plenty of linear features that can be detected robustly. For example, cases 1 and 2 in Fig. 2 had goodness-of-fit values of 0·96 and 0·84; therefore, they had a stronger impact on the EO determination than cases 3 and 4 in Fig. 2. Hence, the resulting EO will presumably fit the image to the vector map as well as possible. It would also be possible to remove the poorly detected linear features completely from the EO calculation by using a threshold value. However, at the moment, all linear features have been used in the EO calculation.

The foremost difference compared with the conventional point-based space resection is that the EO is determined using the coplanarity model presented in Fig. 3 (Mulawa and Mikhail, 1988).

In Fig. 3 $\boldsymbol{\beta}$ is the directional vector of the GCL determined by two endpoints (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2), $\mathbf{c}$ is the vector from a fixed point of the GCL to the perspective centre and $\mathbf{p}$ is the vector from any point of the linear feature on the image to the perspective centre. The coplanarity equation requires these three vectors to lie on the same plane, $|\boldsymbol{\beta}\ \mathbf{c}\ \mathbf{p}| = 0$. Thus, each edge pixel from the scan line algorithm provides one equation to the functional model:

$$\begin{cases} f_1(X_0, Y_0, Z_0, \omega, \phi, \kappa) = 0 \\ \quad\quad\quad \ldots \\ f_n(X_0, Y_0, Z_0, \omega, \phi, \kappa) = 0 \end{cases} . \quad (1)$$

The unknowns in equation (1) are the EO parameters of the aerial image. Because the functional model is non-linear with respect to the unknowns, linearisation is required. Linearisation gives a set of error equations, which in matrix form are $\mathbf{Adx} + \mathbf{f} = \mathbf{v}$, where $\mathbf{A}$ is the design matrix, $\mathbf{dx}$ is the improvement vector, $\mathbf{f}$ contains the values of the functions in equation (1) with the updated EO parameters and $\mathbf{v}$ is the residual error vector. In the least squares adjustment residual $\mathbf{v}^T\mathbf{Pv}$ is minimised, where $\mathbf{P}$ is a matrix containing the weights of the observations. In this case the goodness-of-fit values [0, 1] have been used as weights. However, the line length or line type could also be used. The improvements to the EO parameters are calculated by solving the following matrix equation:

$$\mathbf{dx} = (\mathbf{A}^T\mathbf{PA})^{-1}\mathbf{A}^T\mathbf{Pf}. \tag{2}$$

The procedure to obtain the EO parameters iteratively can be written in the form of the following steps:

(1) Select the initial values for the unknown parameters X_0, Y_0, Z_0, ω, ϕ, κ.
(2) Linearise the functional model **f** using the initial parameters.
(3) Solve the linearised model to obtain improvements.
(4) Update the initial parameters by adding improvements.
(5) Repeat stages 2 to 4 until improvements are small enough.

The output of the automatic refinement is the EO of the aerial image and the expected standard error of the orientation calculated from the functional model. After refinement, the EO is updated and the resulting projected vector locations on the image can be directly observed from the computer monitor. If the EO turns out to be inaccurate, a new refinement with a narrower scan line width can be carried out until the operator is satisfied with the result. Optionally, it is also possible to calculate a new ortho-image using the new EO parameters. The new orientation can also be easily transported to other software, such as a digital stereoplotter.

Implementation

Initially, the implementation of the line photogrammetry software (linephoto) was started in 1998, when the available means of ortho-image production for parcel map updating were studied. One of the possibilities was to use the existing parcel map for determination of the EO of the new aerial images. Thus costly GCP signalisation work could be avoided. Accordingly, the line photogrammetry method was chosen because the parcel map consists of linear features representing parcel boundaries. The results in 1998 showed that the achievable accuracy was very close to the positional accuracy of the existing parcel map. Even incorrectly digitised parcel boundaries could be tolerated to some extent, because they were detected as outliers in the least squares adjustment. Approximately 100 of the parcel boundaries guaranteed that the accuracy tolerance of 2·5 m was satisfied. In 1998 a drawback of the linephoto software was that the parcel boundaries had to be manually digitised from the image, so the EO process was relatively time consuming (Karjalainen and Kuittinen, 1999a, b).

Now the linephoto software has been partly renovated. The actual line photogrammetry engine is still the same, but a new graphical user interface (see Fig. 4) and an automatic line detection algorithm have been implemented.

Test Results

Orimattila Image Block

A line-based orientation was carried out with an image block acquired on 20th August 1998 in Orimattila in southern Finland. The aerial camera used was a Wild RC20 with UAGA-F lens. The flight was planned to be on an imaging scale of 1:32 000 with 60% image and 30% strip overlaps. GPS and IMU data were not available, so the initial EO parameters were roughly estimated using the flight plan and topographical maps.

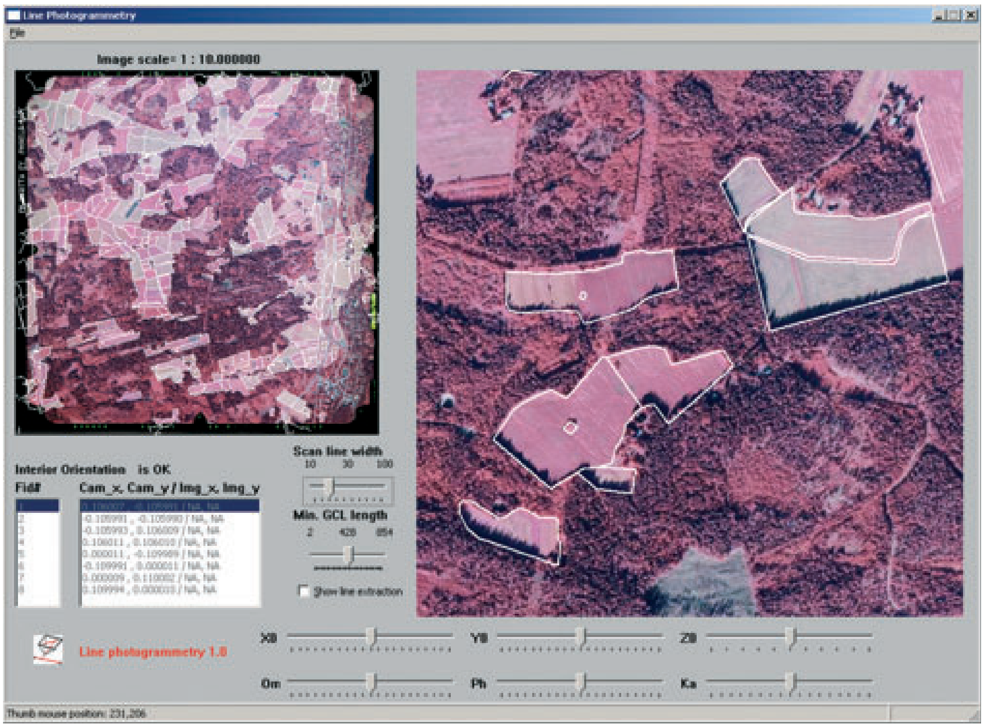

FIG. 4. Graphical user interface of linephoto software.

Reference values for the EOs of the test images were calculated using Intergraph Z/I Imaging ImageStation SSK (version 4.03.00.08). Six images from the whole block were selected as illustrated in Fig. 5. In ImageStation SSK relative orientation was implemented using 48 image-to-image tie points, and absolute orientation was done using 35 signalised *XYZ* ground control points distributed fairly regularly over the whole sub-block area.

The line-based orientation was carried out using linephoto software. GCLs were obtained from the parcel map produced by the Information Centre of the Ministry of Agriculture and Forestry in Finland. According to the quality study by Kaartinen et al. (1999) the *XY* positional accuracy (rmse) of the parcel map is 2·2 m on average. The line-based EO was totally

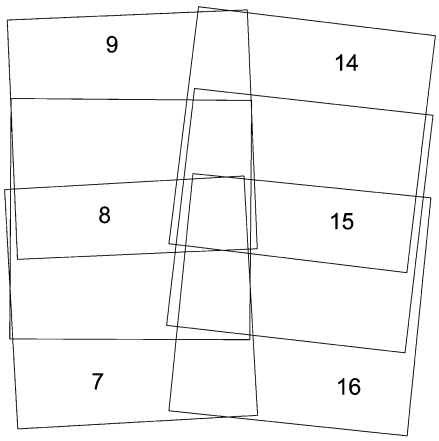

FIG. 5. Footprints of Orimattila test images.

Table I. Estimated accuracies of line-based EOs according to the least squares adjustment.

Image number	X_0 *(m)*	Y_0 *(m)*	Z_0 *(m)*	ω *(gon)*	ϕ *(gon)*	κ *(gon)*	*Number of GCLs*
7	0·723	0·778	0·244	0·008	0·008	0·003	1418
8	0·819	0·809	0·247	0·009	0·009	0·003	1395
9	0·819	0·749	0·241	0·008	0·009	0·003	1703
14	0·972	1·013	0·268	0·011	0·011	0·004	1228
15	1·068	1·010	0·331	0·011	0·012	0·004	1117
16	0·734	0·720	0·267	0·009	0·008	0·003	1695

Table II. Differences in reference and line-based EO parameters.

Image number	ΔX_0 *(m)*	ΔY_0 *(m)*	ΔZ_0 *(m)*	$\Delta\omega$ *(gon)*	$\Delta\phi$ *(gon)*	$\Delta\kappa$ *(gon)*
7	−1·510	6·182	0·409	−0·048	−0·034	0·008
8	2·967	8·214	−2·868	−0·105	0·022	−0·016
9	−4·093	3·363	1·817	−0·025	−0·037	−0·015
14	1·911	−4·270	−2·250	0·052	0·028	0·019
15	0·398	5·378	−1·599	−0·040	0·009	0·048
16	−1·287	−2·709	−5·178	0·090	0·026	−0·066

independent of the SSK orientation. The EO procedures of the linephoto software for each test image were similar to each other. Since maps were used to estimate roughly the initial EOs, a slight manual adjustment using slide switches was needed before automatic EO refinement. Automatic EO was carried out iteratively by gradually narrowing the width of the scan line and increasing the number of GCLs. Table I gives the expected accuracies of the line-based EO parameters according to the least squares adjustment (calculated from the unit weight variance and variance/covariance matrix) and the number of the GCLs used in the final stage of the automatic EO. On the other hand, Table II shows the differences of line-based EO parameters with respect to the ImageStation SSK-based EO parameters. In the final stage of the automatic EO, the values of 20 pixels for scan line width and 10 m for minimum GCL length were used.

The internal accuracy estimates in Table I are significantly lower than the difference values represented in Table II. When the line-based EOs were used to calculate new ortho-images, they seemed to fit the parcel map excellently. Therefore, even though the line-based EO provided a good co-registration of images and parcel map, outer control reveals that there are most likely systematic errors in the parcel map that are directly passed to the line-based EO parameters. When the differences in the line-based and reference EOs are considered (in Table II), the accuracy in the *Y* direction (northing) seems to be somewhat poorer than in the *X* direction (easting). The reason might be that the shadows in the edges of the forests exist mainly in the *Y* direction because the images were acquired at 10 a.m., so the sun was in the south-east at an elevation of 30°. Other possible factors affecting the outer accuracy are the distribution, length and orientation of the GCLs used in the line-based EO. However, these factors were not studied because in this case they would only describe the accuracy of the parcel map itself. More likely, simulation studies would be needed to analyse the effects of the distribution, length and orientation of the GCLs with respect to the line-based EO.

Oblique Aerial Image

The second test was carried out using an oblique aerial image. The test area is located in southern Finland. In this case it was not possible to calculate the reference EO, because the image was a few years old and there were no signalised GCPs in the area at the time of

FIG. 6. Vector map projected on oblique image (left). Oblique ortho-image, vector map and Landsat TM ortho-image (right).

acquisition. Moreover, no direct georeferencing information was available. However, this test provides an example of the situation where only camera calibration and some vector data are available for the EO. It should be noticed that the vector map used in the test consisted of centrelines of the major roads, a few building outlines and parcel boundaries, which were manually digitised from an orthorectified Landsat TM image (pixel size 30 m). The original oblique image and the vector map are shown on the left in Fig. 6. After the linephoto EO, a new ortho-image was calculated; this is shown on the right in Fig. 6.

The oblique ortho-image on the right in Fig. 6 appears to fit quite well into the vector map and TM image. The spatial resolution of 30 m of the Landsat TM differs greatly from the 1 m resolution of the oblique image. Thus, it was extremely difficult to digitise check points for the accuracy assessment. However, judging from a few road junctions and visual inspection, the accuracy of the new ortho-image seems to be as good as the pixel size of the Landsat TM image, which implies that linear features can even be obtained from ortho-images acquired with different sensors.

CONCLUSIONS AND OUTLOOK FOR FUTURE IMPROVEMENTS

The most important advantage of the proposed EO procedure is that no signalised GCPs are required. Instead of GCPs, linear features from the existing vector maps, so-called ground control lines (GCLs), are used. The use of GCLs enables automation, which in this case is the scan line algorithm, which attempts to locate linear features from the image. In practice, the reliability of the procedure appears to be good, because the result can be observed directly from the monitor, where the vector map is projected on the image using the current EO in real time. The automatic EO lasts from a few minutes to hours, depending on the number of lines in the vector map and the memory and processing power of the computer.

The accuracy of the achieved EO parameters depends on the accuracy of the vector map. However, coarse digitising errors in the vector maps can be tolerated to some extent because of the huge volume of linear features. The procedure registers the image to the vector map as well as possible, so any inaccuracies in the vector map such as shifts will also exist in the EO.

Obviously, there are also problems when using linear features as ground control. If GCLs are more or less parallel, then the accuracy in that direction will be most likely poor or even impossible to determine. For example, in some areas of Finland parcels are very elongated, complicating the orientation when only parcel boundaries are used. Hence, the vector map used in the EO should contain diverse data sources including, for example, roads and building outlines as well as parcel boundaries. The number of GCLs required for the successful EO determination depends on the quality of the vector map used. For example, when the Finnish land parcel identification system was applied, the use of approximately 100 parcel boundaries fulfilled the 2·5 m accuracy requirement of the new ortho-image (Karjalainen and Kuittinen, 1999a). Because the edge detection part of the procedure has now been automated, there is no need to restrict the number of GCLs. It is rather a problem of how to use only those linear features in the EO determination that have been correctly detected. For instance, shadows on the images are very difficult with respect to the automatic EO algorithm, because the scan line method can easily confuse the edge of the shadows and the actual control feature. Some of the problems caused by shadows can be avoided by requiring extracted edge pixels to be collinear or by using some appropriate shadow detection algorithm. In any event, in practice the enormous volume of GCLs usually forces orientation towards the correct EO and outliers can be tolerated to some extent.

The proposed method could be improved by removing outliers more efficiently in the least squares adjustment. At the moment, linephoto uses all automatically extracted edge pixels and the weight of the observation is determined by how well the edge pixels fulfil the equation of a line. If the number of linear features is huge then the worst outliers might be removed quite safely. At the moment, in the least squares adjustment the GCLs are assumed to be error free, so it could be improved by using an adjustment model where ground control is expected to have errors, which is useful in cases where the positional accuracies of the different features (roads, parcel boundaries) are known.

It would also be interesting to include other sensor models, such as synthetic aperture radar (SAR), affine or projective transformation. The graphical user interface would be the same, but new subroutines for image-to-ground and ground-to-image coordinate transformations should be included. New functional models for each sensor model would also be needed in order to solve the EO parameters.

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Résumé

On décrit dans cet article un procédé pour déterminer l'orientation externe (O.E.) d'images à partir de cartes numérisées au format vecteur. Ce qu'il y a de plus important dans ce procédé c'est qu'il ne nécessite aucun point d'appui au sol spécialement identifié, étant donné que l'O.E. est effectuée en utilisant uniquement des segments d'appui au sol tirés du système d'information géographique (SIG). Bien qu'il soit possible d'automatiser entièrement le procédé, il est préférable de recourir à une petite assistance par un opérateur pour obtenir une valeur initiale de l'O.E., valeur qui sera introduite dans le processus automatique et n'a pas besoin d'être très précise. La compensation des paramètres initiaux de l'O.E. est extrêmement simple, car la correspondance entre les segments vectoriels sur la carte et leur projection sur l'image est constamment remise à jour en temps réel dans le moniteur de l'ordinateur. On obtient la valeur finale de l'O.E. grâce à une méthode automatique procédant a un balayage linéaire local suivi du positionnement des éléments linéaires ainsi tirés de l'image. Le calcul final de l'O.E. utilise la méthode de photogrammétrie par segments. On a mis en œuvre ce procédé d'O.E. sous la forme d'un logiciel sous Microsoft Windows, et, bien qu'il ne puisse traiter qu'une image à la fois, il constitue un moyen rapide et fiable de déterminer l'O.E. Un essai a montré que la précision obtenue dépendait de la précision du positionnement des éléments linéaires utilisés. Il en résulte que tout décalage dans les coordonnées 2D des éléments vectoriels tirés de *la carte se répercutait directement sur les paramètres de l'O.E. en l'absence de tout autre point d'appui.*

Zusammenfassung

In diesem Beitrag wird ein Verfahren zur Bestimmung der äußeren Orientierung (EO) von Bildern auf der Basis digitaler Vektorkarten vorgestellt. Als wichtigstes Merkmal ist hervorzuheben, dass keine signalisierten Passpunkte (GCPs) benötigt werden, da die äußere Orientierung allein mit Hilfe von Passlinien (GCLs) durchgeführt wird, die aus einem Geographischen Informationssystem (GIS) bereitgestellt werden. Das vorgeschlagene Verfahren könnte sogar vollständig automatisiert werden, allerdings ist vorerst noch eine gewisse interaktive Führung in der Initialisierung erforderlich, um ausreichend genaue Näherungen für die Automatisierung der Bestimmung der äußeren Orientierung bereitzustellen. Die manuelle Einstellung der Näherungen ist sehr einfach, da die projizierte Lage der Kartenvektoren im Bild in Echtzeit am Monitor aufdatiert wird. Nach einer Lokalisierung linearer Merkmale werden die endgültigen Parameter der äußeren Orientierung mit Hilfe von Linienphotogrammetrie ermittelt. Die Software wurde in Microsoft Windows Umgebung programmiert und obwohl nur jeweils ein Bild bearbeitet werden kann, bietet sie eine zuverlässige und schnelle Möglichkeit die Parameter der äußeren Orientierung weitgehend automatisch zu bestimmen. Die Testergebnisse haben jedoch die Abhängigkeit der Genauigkeit dieser Parameter von der Lagegenauigkeit der linearen Merkmal nachgewiesen. Damit können z.B. 2D-Koordinatenverschiebungen der Kartendaten die Parameter der äußeren Orientierung negativ beeinflussen.

Resumen

Este artículo muestra un procedimiento para determinar la orientación exterior de imágenes utilizando cartografía vectorial digital existente. La característica más importante es que no son necesarios los puntos de control señalizados porque la orientación exterior se obtiene exclusivamente de líneas de control (LC) obtenidas a partir de Sistemas de Información Geográficos (SIG). Aunque el procedimiento de orientación exterior propuesto podría ser completamente automático, se hace necesaria una cierta intervención del operador en el ajuste de la orientación exterior inicial, que debería ser moderadamente exacta antes de automatizar el procedimiento. Sin embargo, el ajuste de los parámetros iniciales de orientación es bastante fácil, porque las localizaciones proyectadas de los vectores sobre la imagen se actualizan en tiempo real en el monitor. Por último, la orientación definitiva se obtiene utilizando un método automático que usa una técnica de escaneado local de líneas que trata de encontrar entidades lineales en la imagen. La orientación definitiva se calcula utilizando el método fotogramétrico para líneas. Nuestro procedimiento de orientación exterior fue desarrollado como una aplicación en el entorno Microsoft Windows y, aunque el programa puede procesar sólo una imagen a la vez, proporciona una forma fiable y, al mismo tiempo, rápida de obtener la orientación exterior. El resultado de nuestro ensayo mostró que la exactitud alcanzada depende de la exactitud posicional de las entidades lineales utilizadas. Por lo tanto, los desplazamientos de las coordenadas 2D en los mapas vectoriales se transfieren directamente a los parámetros de orientación exterior sin ningún otro control.

