The use of Linear Features as Ground Control Information for the Georeferencing of Old Aerial Photos

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Key words: Old aerial photos, Georeferencing, Linear features, Photogrammetry

SUMMARY

Old aerial photos are necessary for applications that involve detection of land use changes over time and/or detection of old constructions or other topographic features. The accurate location and measurement of Ground Control Points on such photos is difficult due to the fact that often the area of study was changed due to human activities over the years. This paper addresses the problem of the ambiguous identification of Ground Control Points on old aerial photos using linear features such as road edges. Linear features, in contrast to points, tend to persist over time and thus they can be exploited as an alternative form of ground control information. The transformation between the 3D object space and the 3D model space of a stereo-pair of old photos is computed by matching 3D linear features of arbitrary geometry (free-form linear features) using the Iterative Closest Point algorithm within a least squares adjustment framework. The method is tested by the investigation of the accuracy of the georeferencing of a stereopair of aerial photos taken in 1945, using linear features. The area of study is located at Chalkidiki region, Northern Greece. As reference data, a stereo pair of recent high resolution satellite images was used, as well as topographic maps at a scale of 1:5,000. Linear features, mainly roads, were extracted from the stereo-model of aerial photos of 1945. The same features were also digitized on the oriented stereo pair of satellite images and on the topographic maps, in order to constitute reference data for the georeferencing process. The accuracy computed for the georeferencing of the aerial photos of 1945 using the method of matching linear features were much better than those of the aerial triangulation method using solitary Ground Control Points.

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1. INTRODUCTION

The use of old aerial photos is necessary for applications that involve detection of land use changes over time and/or detection of old constructions or other topographic features. In Greece, according to legislation, the aerial photos of 1945 are used for the production of orthophotomaps with which the forest land is defined and protected, and disputes about land legal rights are resolved. The reason why aerial photos of 1945 are used for this purpose is that they are the oldest aerial photos covering the whole country. Thus, 1945 constitutes a reference year according to which the land is characterized as forest land or not.

However, the aerial photos of 1945, or historical aerial photos as they are often called, exhibit some major problems that reduce their georeferencing accuracy and therefore the accuracy of the orthophotos produced by them. Such a problem is the difficulty to accurately locate and measure Ground Control Points (GCPs), necessary for the georeferencing. This happens due to the low sharpness of the old aerial photos, the usually small scale of the photos and the fact that often the area of study was changed due to human activity over the years.

This problem can be addressed using linear features, like roads and streams, instead of salient points, as Ground Control Information (GCI). Linear features exhibit some attractive advantages, such as their abundance in the man-made and physical environment, the easiness and reliability of detection and matching compared to points, even if a long period of time has passed, and the fact that they provide a continuous source of information (Heikkila, 1991; Schenk, 2004; Habib et al., 2004; Vassilaki et al., 2012). In this paper the method describing the process for the georeferencing of old aerial photos using linear features is presented. The method is based on the matching of common linear features between the old aerial photos and recent data, such as satellite images or topographic maps (Vassilaki et al. 2008; 2012). An application test is done in order to evaluate linear features as GCI, and the evaluation of results and some useful conclusions are presented.

2. METHODOLOGY

In order to perform the georeferencing of a photo, GCI (usually GCPs) must be known both in the 3D object space, and in the 2D image space or the 3D model space of a stereo-pair. The GCI is used to compute either the 3D-2D projection transformation between the 3D object space and the 2D image space, or the 3D rigid similarity transformation between the 3D object space and the 3D model space. In this paper the necessary GCI, known in the 3D object space and in the 3D model space, is in the general form of Free-Form Linear Features (FFLFs), namely hereinafter Ground Control Linear Features (GCLFs). GCLFs are linear features of arbitrary geometry such as road edges and coastline and they are defined as a collection of consecutive nodes of no regularity in the 3D object space (X,Y,Z) and in the model space (Xm,Ym,Zm). The nodes of GCLFs in the two spaces certainly vary widely in number and position, as the two types of GCLFs have been extracted by different datasets and with different methods. For example, the nodes of a GCLF in the object space may have been measured by mobile mapping systems, or may have been extracted from existing maps or GIS data or even they may have been extracted from remote sensing data. The nodes of its corresponding GCLF in the model space are usually digitized by stereoscopic measurements in a digital photogrammetric workstation. Thus it is not possible to directly correlate the two types of GCLFs using their nodes.

In this paper the method proposed by Vassilaki et al (2008; 2012) is used. The method is based on Iterative Closest Point (ICP) algorithm (Besl and McKay, 1992; Zhang, 1994), blending brute force (Sedgewick, 1992) and divide-and-conquer (Knuth, 1997) techniques. The method computes closest point pairs between two heterogeneous FFLFs. One FFLF is split to a large set of consecutive interpolated points, each one very close to its previous and its next point. Then, the distances of all these points to a node of the other FFLF are computed, and the point with the least distance is the closest point to the node. The pairs of closest points are used to compute the parameters of the similarity transformation between the two FFLFs within a Least Squares Adjustment framework. The computed transformation is applied and the two FFLFs are brought closer together. The process is repeated until convergence. The steps of the method are summarized as:

i) computation of the closest points,
ii) computation of the georeferencing,
iii) application of the georeferencing, and
iv) check of the error against a threshold.

The method was embedded into ThanCad (Stamos, 2007), a free/open source CAD, for convenience and user friendliness.

The 3D rigid similarity transformation which is employed here, consists of three translations (ΔX, ΔY, ΔZ), three rotations (Ω,Φ,K) and a uniform scale (s) between the 3D object space (X,Y,Z) and the 3D model space (Xm,Ym,Zm):

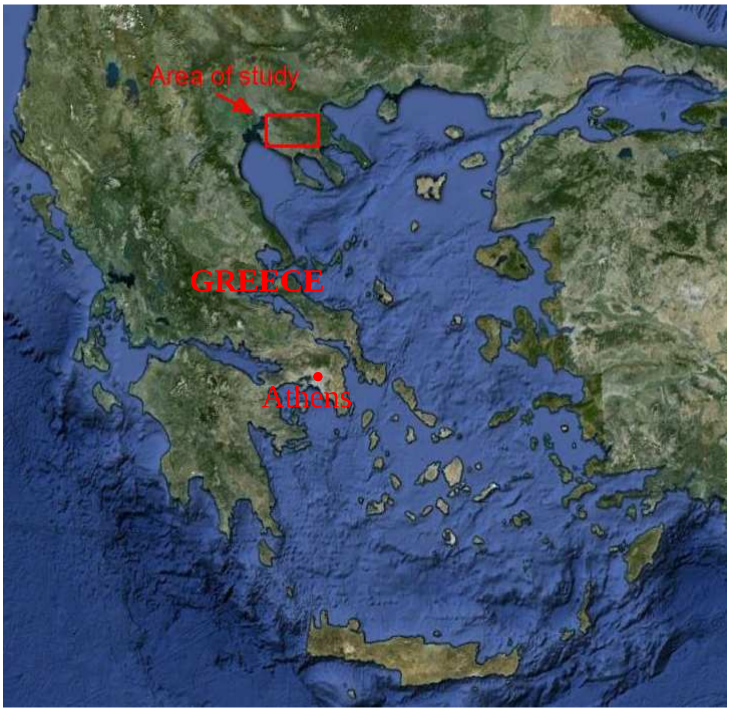
$$\begin{bmatrix} X \\ \mathrm{Y} \\ \mathrm{Z} \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta \mathrm{Y} \\ \Delta \mathrm{Z} \end{bmatrix} + s \cdot \begin{bmatrix} \cos\Phi\cos\mathrm{K} & \cos\Phi\sin\mathrm{K} & -\sin\Phi \\ \sin\Omega\sin\Phi\cos\mathrm{K} - \cos\Omega\sin\mathrm{K} & \sin\Omega\sin\Phi\sin\mathrm{K} + \cos\Omega\cos\mathrm{K} & \sin\Omega\cos\Phi \\ \cos\Omega\sin\Phi\cos\mathrm{K} + \sin\Omega\sin\mathrm{K} & \cos\Omega\sin\Phi\sin\mathrm{K} - \sin\Omega\cos\mathrm{K} & \cos\Omega\cos\Phi \end{bmatrix} \cdot \begin{bmatrix} Xm \\ Ym \\ Zm \end{bmatrix}$$

3. APPLICATION TEST

3.1 Study area

The study area is located at Polygyros, in Chalkidiki region, Northern Greece, near the roots of the mountain Cholomontas, and it is characterized for its mountainous terrain and its dense forests (Figure 1). It has sites of natural beauty, which make it an important touristic center.

Population growth is positive and the touristic development of the area is continuous. As a result there has been expansion of the road network, as well as intense building activity lately, with a lot of hotels and houses having been constructed. So, it is obvious that there have been significant spatial changes in the human and natural environment of the region during the last decades. Nevertheless, some roads or streams have not changed in their general form.



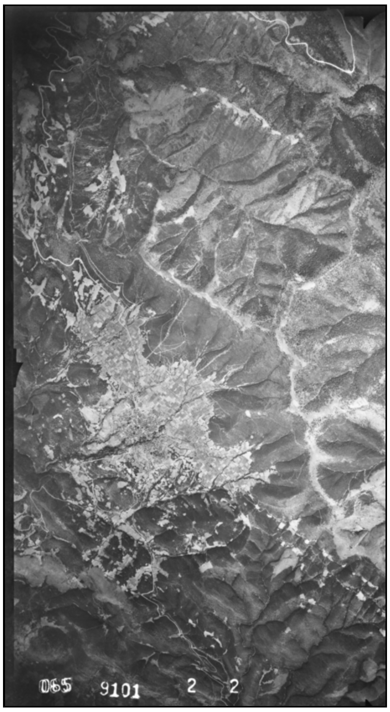


Figure 1: The location of the study area (left) and the study area in an aerial photo taken in 1945 (right)

3.2 Datasets

The available data were:

- the diapositives of greyscale aerial photos taken in 1945, at a scale of approximately 1:42,000, which were scanned with a 1200 dpi resolution using a photogrammetric flatbed scanner,
- a stereo pair of satellite Cartosat-1 panchromatic images, with a resolution of 2.5 m ground sampling distance, captured in August 2006, and
- four analogue sheets of the national-wide medium scale topographic maps, at a scale of 1:5,000, compiled in 1980.

Both the stereo pair of satellite images and the topographic maps were used for the extraction of the linear features, so as to constitute reference data for the georeferencing process. The topographic maps were also used in order to determine the geodetic coordinates of GCPs and Check Points (CPs), necessary at various stages of the application test.

3.3 Georeferencing of the old aerial photos using GCLFs

For the application of the proposed procedure common linear features must be identified on the old aerial photos and on the other datasets (reference data). This was done with visual comparison of the old aerial photos with the satellite images and the topographic maps. As the density of roads in the study area was low in 1945, only 15 common linear features were detected, 12 roads and 3 streams. The roads were either national and municipal roads, or rural and forest roads. Their detection was difficult, especially between the aerial photos of 1945 and the satellite images of 2006 (Figure 2), because of the 60 years time interval between these two datasets. The distribution of the 15 linear features in the area of study is shown in Figure 3.

Figure 2: The same linear feature, as it is shown in the aerial photos of 1945 (left) and in the recent satellite images of 2006 (right)

For the selected linear features to be used for the matching process, 3D coordinates of their nodes have been digitized for each of the datasets. So, for the stereo pair of the old aerial photos the relative orientation was calculated, in a digital photogrammetric workstation, and the edges of the 15 linear features were digitized on the stereo-model. In this way, the 3D model coordinates (X_m, Y_m, Z_m) of the nodes of linear features' edges were measured, in an arbitrary coordinate system with arbitrary orientation and scale. The coordinates of the axis of each linear feature were calculated using skeletonization techniques.

The reference linear features were extracted using both the stereo pair of satellite images (Case I) and the topographic maps (Case II).

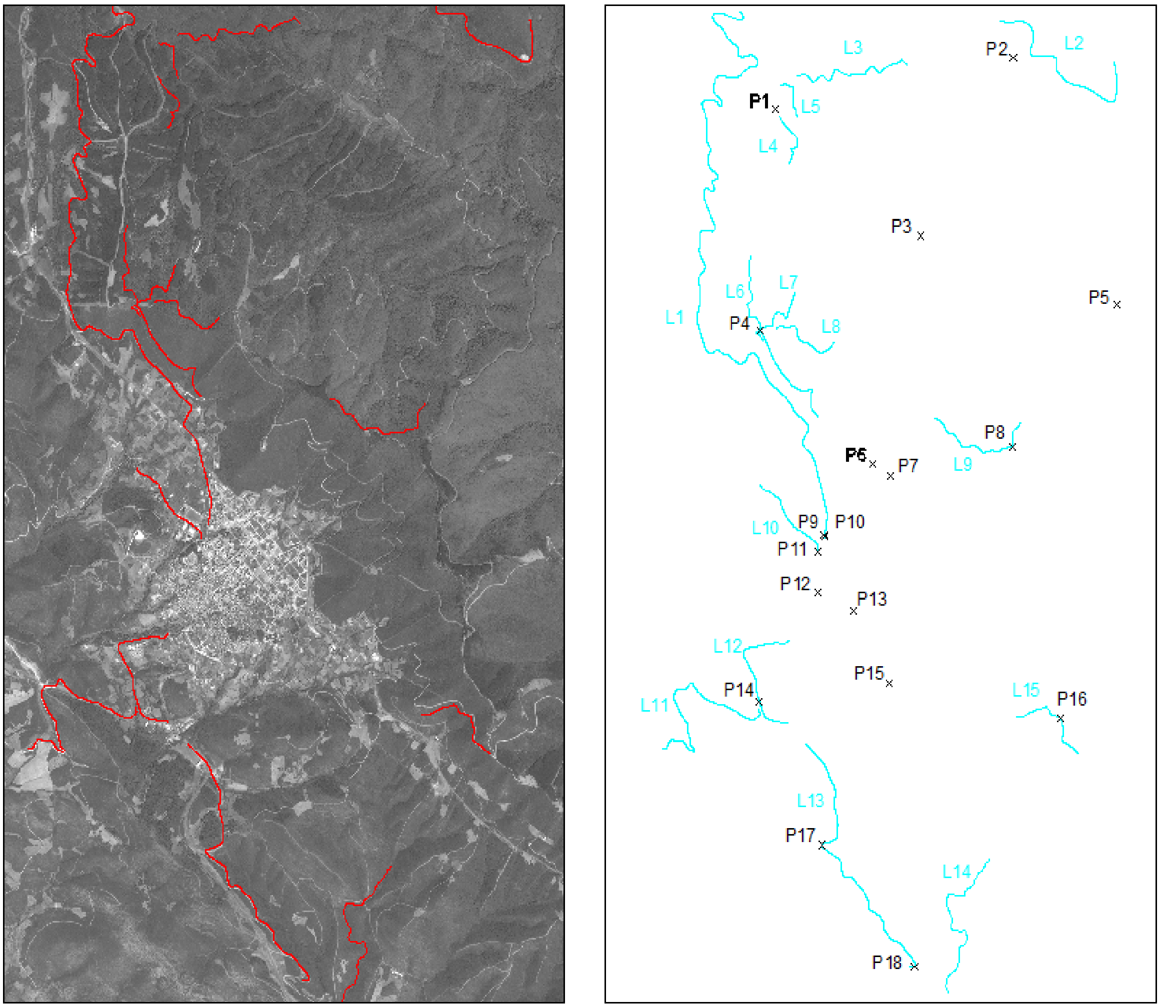


Figure 3: The distribution of the 15 linear features at the area of study, on the recent satellite image (left) and the distribution of the 18 independent CPs (right)

In Case I the georeferencing of the stereo pair of satellite images was done, using Rational Function Models and 13 GCPs (with coordinates in the Greek Geodetic Reference System, GGRS87), regularly distributed at the study area. The achieved accuracy, using 4 independent CPs, was 5 m or 2 pixels (as the spatial resolution of the satellite images of Cartosat-1 is 2.5 m) for the planar position and 3 m for the vertical position. This relatively low accuracy of georeferencing is due to the fact that the GCPs (as well as the CPs) were extracted from the topographic maps. However, this accuracy is sufficient for the requirements of the application test. The road and stream edges were stereo-digitized on the georeferenced stereo pair of satellite images and the axis of each linear feature was calculated from its edges through the use of skeletonization techniques. The old aerial photos were georeferenced through matching of:

- only the left edges of the 15 linear features,
- both edges of the 15 linear features, and
- the axes of the 15 linear features.

In Case II, the 15 linear features were digitized on the topographic maps. For the most of these linear features only their axes were digitized, since their edges were not always available. However, when the edges were available, skeletonization techniques were used for the calculation of the axis. The topographic maps were transformed from their old coordinate system (HATT) to the Greek Geodetic Reference System (GGRS87 - EGSA87). The accuracy of the transformed digital maps was 2-2.5 m. The vertical accuracy of the maps was estimated to 2 m (half of the contours' interval which is 4 m). So, the planar coordinates of the nodes describing the linear features are calculated in GGRS87. The elevation of each node is calculated through interpolation using the elevation information of the map (contour lines and individual elevation points). The georeferencing of the old aerial photos was done through matching the axes of the 15 linear features.

Since the extraction of road and stream edges and axes was done using the arbitrary stereo-model coordinate system of the aerial photos of 1945, it was necessary to have a good initial estimation of the similarity transformation for the ICP algorithm. This information was acquired by using about the same reference system for the stereo-model of aerial photos of 1945, and for the stereo pair of satellite images or the topographic maps. Practically that meant that in each one of the two cases (I and II), all the linear features had to be roughly pre-aligned manually, in order a first approximation of their relative position to be computed. Otherwise ICP would not converge.

In both cases (I and II) the matching was done separately for each pair of corresponding edges or axes of each linear feature and the three-dimensional similarity transformation between them was computed, as well as many pairs of corresponding points. These points (of all linear features) were used for the computation of the absolute orientation of the stereo-model of the old aerial photos, and therefore for its georeferencing. Figure 4 presents the matching results for the axes of three linear features (which exhibit the highest planar RMSE) at the matching process at Case II.

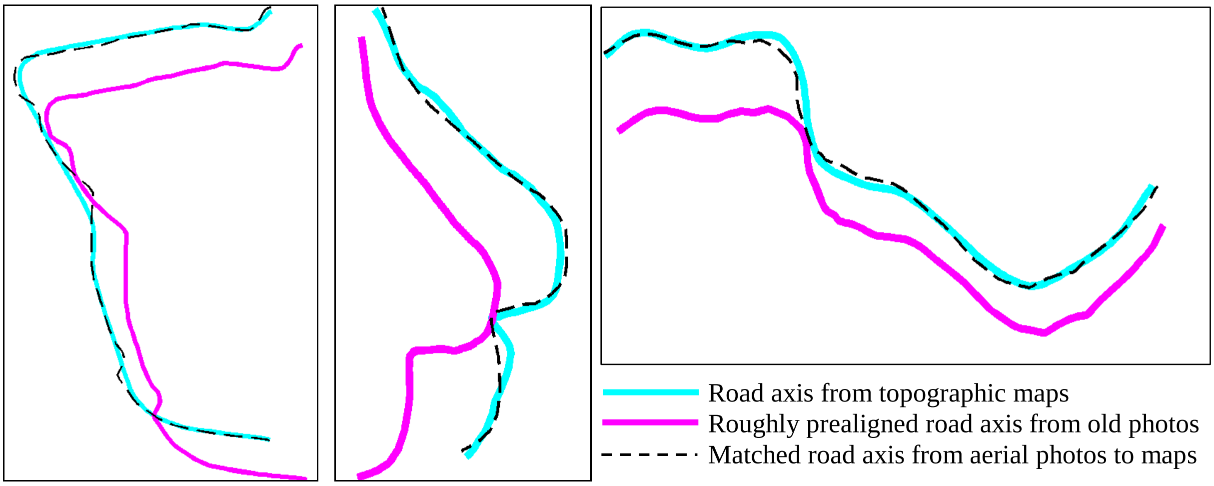


Figure 4: Matching results at Case II, for the three road axes which gave the highest RMSxy

The achieved georeferencing accuracy for the historical aerial photos was evaluated using 18 independent CPs, detected from the topographic maps (Figure 3 right). The results are presented in Table 1.

Georeferencing	RMSE X (m)	RMSE Y (m)	RMSE XY (m)	RMSE Z (m)
A. Use of 15 linear features				
1. Matching the left edges (Case I)	7.64	8.04	11.09	4.31
2. Matching both edges (Case I)	6.93	7.97	10.56	4.74
3. Matching the axes				
Case I (satellite images)	6.94	7.98	10.58	5.03
Case II (topographic maps)	6.43	7.83	10.13	3.21
B. Aerial triangulation, using of 6 GCPs	5.86	15.89	16.94	16.88

Table 1: The results at the independent CPs after the georeferencing of the old aerial photos

3.4 Georeferencing of the old aerial photos using GCPs

The georeferencing of the historical aerial photos was also done using solitary GCPs and the aerial triangulation method, in order to compare the achieved accuracies using linear features and salient points as GCI. The detection of GCPs and independent CPs from the topographic maps was a difficult, tedious and time consuming process, since the difference between the acquisition times of the old aerial photos and the maps is 35 years. There were few points that could be reliably located on the old aerial photos, as during this period of time the natural and human environment of the study area changed significantly. The problem was even harder because of the mountainous terrain of the area. Totally, 6 GCPs and 14 CPs were used for the georeferencing of the old photos. Most of them were road intersections and stream sections, and they were regularly distributed at the area of study. These points were the same with the independent CPs used to evaluate the georeferencing accuracy of the old aerial photos with linear features. The RMSE of the CPs is presented in Table 1. The low accuracy achieved by the solitary GCPs (aerial triangulation method) is explained by the unreliable location of the GCPs and CPs on the aerial photos and the unknown interior orientation of the camera used.

4. EVALUATION OF THE RESULTS

According to the results presented in Table 1, the planar accuracy of the GCLF georeferencing is 10-11 m and the vertical accuracy is 3-5 m. The vertical accuracy is better than the planar accuracy. This discrepancy can be explained due to:

- the planar uncertainty of the GCLFs, e.g., due to road widening; the elevation of the road generally remains unaltered by the widening
- the ambiguity of the planar position of the CPs, e.g., points on road intersections; due to the small slope of the roads, this ambiguity does not affect the vertical position of the CPs.

In Case I, the RMSE using both edges or the axes of the linear features are identical, and slightly better than the RMSE using only one edge. Also, the behavior of the ICP algorithm with respect to the convergence progress and the number of iterations required is the same whether using the edges or the axes of the linear features (Figure 5).

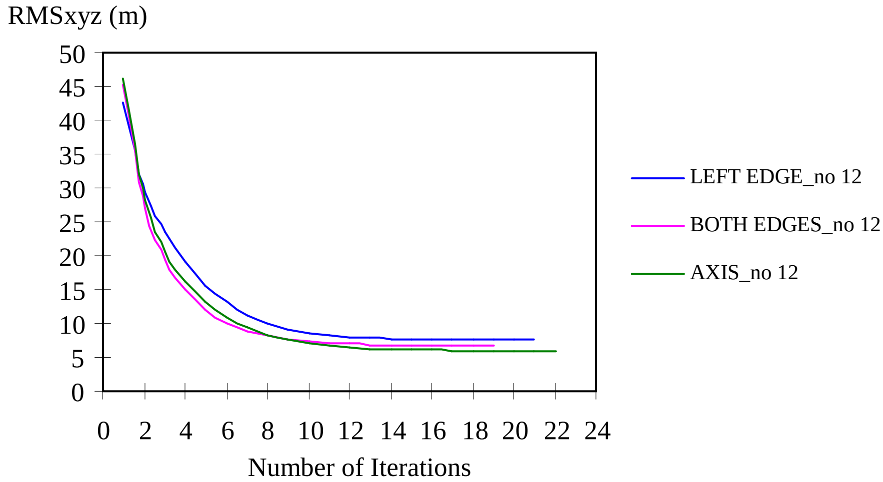


Figure 5: The convergence progress of the ICP algorithm, for the linear feature n. 12, Case I

In Case II, where the axes of the linear features from the topographic maps were used, the RMSE is lower. Relatively to Case I, where the axes of the linear features from the stereo pair of satellite images were used, Case II is slightly better regarding the planar RMSE, and clearly superior regarding their vertical RMSE. This was expected, since the georeferencing planar and vertical accuracy of the stereo pair of satellite images is 5 m and 3 m respectively, whereas the accuracy of the topographic maps is 2-2.5 m and 2 m respectively. Moreover, the maps were designed in 1980, a date which is closer to 1945 than the year 2006, when the satellite images of Cartosat-1 were acquired. Therefore, the common linear features detected between the historical aerial photos and the topographic maps, particularly the common roads, are less likely to have changed their planar position or elevation, than those detected on the satellite images.

Finally, in comparison with the solitary GCPs, the use of linear features for the georeferencing of the old aerial photos, independently from the origin of the reference linear features, has led to significantly better planar and vertical accuracy (Table 1). In particular the vertical accuracy using the linear features is 3-4 times better than the accuracy using solitary GCPs. The results show that the ambiguity on the identification of the GCPs does not apply to the linear features, while the uncertainty due to the multitemporal character of the datasets is counterbalanced by the sheer volume of information provided by the linear features.

5. CONCLUSIONS

Linear features are deemed as appropriate to replace salient points for the georeferencing of the historical aerial photos, especially when it is difficult or impossible to find GCPs, such as in mountainous areas or in areas with intense human activities. The better accuracies achieved with the proposed method, in conjunction with the easier detection of linear features at aerial photos, relatively to individual points, constitute major advantages. Also, it is a cost efficient procedure since no field measurements are required but only a topographic map of the area or an oriented stereo pair of recent aerial or satellite images.

A disadvantage of the method is the time consuming procedure for the location and the manual extraction of the common linear features on the historical aerial photos and the reference data). However, similar and in some cases much bigger difficulty exists in the location of GCPs, for the aerial triangulation adjustment. Also, semi-automated techniques for the detection and extraction processes of linear features may be used.

In addition, using the proposed method, the corresponding points of FFLFs, the coordinates of which were computed as a subproduct during the matching process, could be used as GCPs for the georeferencing of the historical aerial photos with a conventional point-based method aerial triangulation software.

Nevertheless, further investigation should be done using the proposed method on other areas with a variety of characteristics; comparative studies of the achieved results from aerial triangulation using GCPs, should be done. As the historical aerial photos have an unknown interior orientation, the investigation of the impact of self-calibration procedures would be of special interest. Finally, it is worth investigating the possibility of improving the proposed method by calculating the georeferencing parameters by using a network of linear features (Vassilaki et al., 2009) instead of defining the 3D similarity transformation from each one of the linear features separately.

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