RECOVERY OF THE GEOMETRY OF HISTORICAL AERIAL PHOTOS ASSOCIATING SELF-CALIBRATION WITH GROUND CONTROL LINEAR FEATURES

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ABSTRACT

This paper addresses one of the hardest problems of multitemporal image analysis: the recovery of the imaging geometry, both the interior and the exterior, of historical aerial photographs, using ground control information from recent data, e.g., orthoimages and the corresponding DTM. Linear features of arbitrary geometry such as road edges are used as Ground Control Information instead of the discrete points which are the regular case in image orientation analysis. In order to overcome the absence of the calibration report of the camera which collected the historical photographs two transformation models are used: the method of self-calibration method using the Collinearity Equations, and the Direct Linear Transformation. The problem is formulated and the proposed method is established and tested with real world data sets. The time interval between the collection of the historical photographs and the recent data (orthoimages) is almost 65 years. Future research issues are also discussed.

INTRODUCTION

Earth's surface monitoring deals with the evolution of natural and anthropogenic phenomena through time. The most objective and descriptive way to monitor the evolution is through multitemporal remote sensing data. Series of aerial and satellite images acquired in the past are used to monitor forests areas, the coastal zone, ice glaciers, land surface dynamics and change detection. Particularly, old (historical) photographs are used for boundary disputes and for environmental land and estate monitoring and planning, as an objective witness over time. Combined with more recent data, historical photographs enable the evaluation of a certain phenomenon, the estimation of its future trends and finally the planning to protect it or protect the environment from it. The biggest the time difference of the multitemporal data, the more reliable the estimation of the phenomenon and the better the planning.

However, the recovery of the imaging geometry of historical images is a time-consuming and laborious process and it is hard to meet high standards of accuracy. A recent example is the Portugal's aerial images repository reclaim (4). The main reasons for these difficulties are:

- the lack of camera calibration reports. It refers to the camera's geometric parameters, as documented in the camera calibration report. In the case of historical images, the camera's parameters may be partially available or they may even be lost during the years or never documented.
- the wide spatial changes occurred on Earth' surface since the image capture and the present day. The time interval may be 60 or more years and thus it is hard to identify homologous points on Earth's surface and on the photo.

Moreover, characteristics inherent to the historical photographs, such as small image scale, old-fashioned radiometric characteristics, absence of FMC, use of reprints and deterioration due to the aging of the film and the storage conditions, make the identification of homologous points harder. Homologous points in the Earth's surface and on the photograph, namely Ground Control Points (GCPs), are necessary in order to recover the exterior geometry (exterior orientation) of the image at the time of the acquisition. Generally GCPs are collected through GPS ground survey. However this is seldom possible due to the large spatial changes. An alternative way to collect GCPs, is to identify homologous points on the photogrph and on old maps, which are closer to the photograph, in time. In some cases historical field data may be available (4); its use may help but the field data, old by itself, does not necessarily guarantee adequate co-registration with contemporary remote sensing and geospatial data.

The objective of this paper is to investigate the use of linear features of arbitrary geometry as a source of ground control information, instead of the use of salient points. Specifically, the problem is formulated to use linear features to recover the imaging geometry, both of the interior and exterior, of historical aerial photographs. The results are compared to those of the salient points formulation, in terms of accuracy, reliability and workability. Finally, issues of future research are discussed.

PROPOSED METHOD

The proposed method combines the self-calibration procedure with a general procedure which uses Linear Features as Ground Control Information (GCI) within a (Iterative Closest Point) ICP-based Least Squares Adjustment (LSA) framework (5, 6, 7).

The most general representation of linear features (GCLFs) is through nodes of no regularity, which are linked with an arbitrary type of curve (linear, splines, rational polynomials, NURBs, etc) suited to the problem. A pair of homologous GCLFs shares no homologous nodes, as they are produced by different sensors and methods. Splitting the GCLFs to large number of dense consecutive interpolated points (which cause no additional error), homologous points may be established, as pairs of closest points between the two GCLFs (5, 7). The homologous points are used to compute the parameters of the transformation, which is used to bring the GCLFs closer together. The process, called Iterated Closest Point (ICP) algorithm, is repeated until convergence (1, 9). An initial approximation of the transformation, which is needed to trigger ICP convergence, is provided by the similarity transformation which is determined exploiting physical characteristics of GCLFs, namely their centroids, their endpoints and their lengths (7). In the case of the projection transformations (3D-2D), the same initial approximation is used after projecting the object coordinates to the xy plane while saving the association between object and projected coordinates at the same time (7). Networks of GCLFs improve the accuracy of the method as they potentially cover the photograph more fully than a single pair of GCLFs. Homologous GCLFs are determined as the ones with the least “distance” which is defined as the largest value of the Euclidean distance of the centroids or the endpoints or the lengths of two GCLFs (6). As all GCLF pairs share the same transformation, one pair of GCLFs may be used manually to provide the first approximation in order for this procedure to work (8).

In the case of historical photographs it is necessary to use transformation models which do not need the a priori knowledge of the interior orientation parameters (camera calibration report). These are the photogrammetric resection with self-calibration using Collinearity Equations (Equation 1) and the Direct Linear Transformation (DLT) (Equation 2):

$$x - x_0 = -c\frac{(X - X_0)r_{11} + (Y - Y_0)r_{12} + (Z - Z_0)r_{13}}{(X - X_0)r_{31} + (Y - Y_0)r_{32} + (Z - Z_0)r_{33}}, \quad y - y_0 = -c\frac{(X - X_0)r_{21} + (Y - Y_0)r_{22} + (Z - Z_0)r_{23}}{(X - X_0)r_{31} + (Y - Y_0)r_{32} + (Z - Z_0)r_{33}} \quad (1)$$

$$x = \frac{a_1X + a_2Y + a_3Z + a_4}{c_1X + c_2Y + c_3Z + 1}, \qquad y = \frac{b_1X + b_2Y + b_3Z + b_4}{c_1X + c_2Y + c_3Z + 1} \quad (2)$$

where (x, y) are the 2D image space coordinates of a point P, (X, Y, Z) are the 3D object space coordinates of the point P, c is the calibrated focal length (or camera constant), (x_0,y_0) is the offset from the fiducial-based origin to the perspective center origin (principal point), (X_0,Y_0,Z_0) is the position of the center of perspective (or camera station) in object space and (r_{ij}) are the elements of the rotation matrix $R(\kappa,\varphi,\omega)$ from the object space to the image space (2). For the solution with the photogrammetric resection (Equation 1), the principle point may be considered that is identical with the center of the photograph ($x_o=y_o=0$) and that the radial distortion is insignificant, without significant impact on the accuracy. So, the remaining unknowns are 7 (c and the parameters of the exterior orientation X_o, Y_o, Z_o, ω, φ, κ). In the DLT solution the unknowns are 11 (the a_i, b_i, c_i coefficients). In both models X, Y, Z and x, y are known for a large number of points provided by ICP.

Figure 1: Data sets: aerial photograph captured in 1945 (left), orthoimage made from aerial images collected in 2008 (right).

DATA SETS AND AREA OF STUDY

The proposed method was tested using: a) the diapositive of a greyscale aerial photograph, b) a recent medium scale (1:5,000) orthoimage with the corresponding DTM (Figure 1). The average scale of the photograph is 1:42,000 and it was captured in 1945. The diapositive was scanned using a photogrammetric flatbed scanner with 1200dpi (~ 21μm/pixel) resolution which is the regular resolution for scanning analogue photohraphs. The calibration report of the camera which captured the historical photographs is no longer available. The medium scale orthoimage and the corresponding DTM were created using aerial images which were collected in 2008. The pixel size of the orthoimage is 0.5 m while the pixel size of the DTM is 5 m. The planar accuracy of the orthoimage is 1.5 m and the vertical accuracy of the corresponding DTM is 2 m. Additionally, the use of a medium scale topographic map of scale 1:5,000, compiled in 1970 was required. The accuracy of the map is the same with the accuracy of the orthoimage and its corresponding DTM. The data sets depict a region north-east of Athens which has steep mountainous terrain. The region is covered by typical southern Europe vegetation (thin) and two towns. A small part of the historical photograph is covered by the sea, and the average ground elevation is 270m. The large spatial changes between the data sets are evident in Figure 1, where the built up area of the orthophoto is absent in the historical photo.

RESULTS

In order to use the proposed method to recover the imaging geometry of the historical photograph, twenty one homologous GCLFs of adequate length (0.5 Km to 12 Km) were identified between the historical aerial photograph and the recent orthoimage, most of which are road edges (Figure 3).

For both data sets the road centre line was computed from the edges using skeletonization techniques. The heights of the centre lines of the orthoimage were interpolated from the available DTM. The computation of the image geometry was done twice: once using the Collinearity Equations and once using the DLT. The accuracy was evaluated using 46 independent Check Points (CPs). The results for the planar errors of CPs are: $RMSE_{(XY)}$ = 6.5 m using the Collinearity Equations and $RMSE_{(XY)}$ = 6.2 m using the DLT. These results are quite good as usually the accuracy achieved with this type of photographs is 10-15 m and sometimes even worse (20-25 m). In Figure 2, where some of the 3D-2D matching results are shown, the multitemporal nature of the datasets is evident.

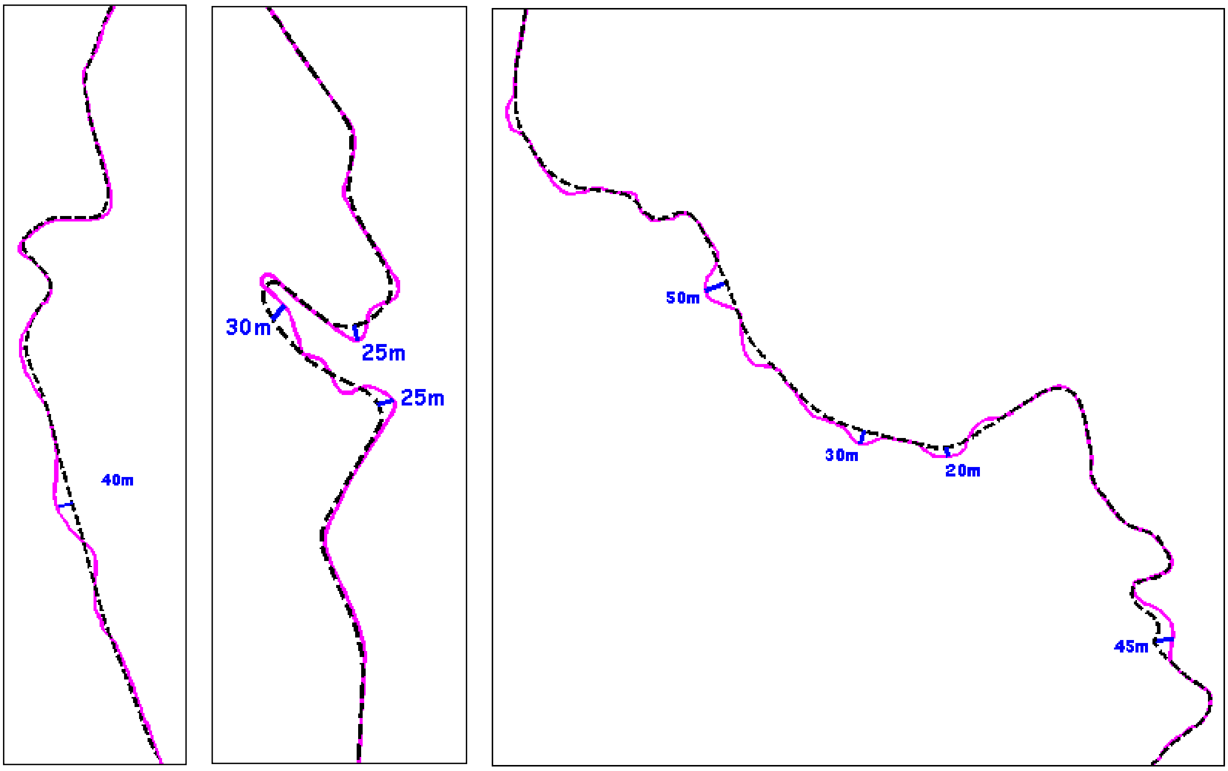

Figure 2: GCLFS on the historical photograph (in magenta), projected GCLFs from the orthoimage and the corresponding DEM using the computed transformation (in black).

The comparison of the achieved results using GCLFs with the results from the georeferencing of the historical photograph using GCPs is considered to be necessary for further evaluation of the proposed method (3). The first derived conclusion, from this comparison, is that the identification of GCPs is a quite laborious process with uncertain success. For the particular application, in order to increase the degree of success and reliability in determining more GCPs, an "interpolation-in-time" process was used. A topographic map compiled in 1970 was interpolated between the historical photograph (1945) and the recent orthoimage (2008). Thus the 65 years time interval between the data sets was split to two time intervals: 25 years and 40 years. The "interpolation-in-time" process had also been used in former unpublished research of the authors using blocks of aerial photographs: recent orthoimages were used for the orientation of blocks of aerial images of 1960 and then the oriented stereo-models of 1960 were used for the orientation of the historical photographs (1945). It is a quite laborious process, hard to be applied for operational cases, since various multimodal data sets have to be acquired and processed. In the current case, the topographic map was preferred because it is a standard accuracy mapping product. Eleven GCPs were identified and used for the georeferencing of the historical photo. The planar accuracy was evaluated with the 46 independent CPs. The RMSE of the CPs is 7.2 m for the Collinearity

Equations and 7.3 m for the DLT. The especially sophisticated but also time-consuming procedure for the selection and identification of the GCPs has led to these results that may be considered as the best possible results using GCPs for the georeferencing of this historical photo.

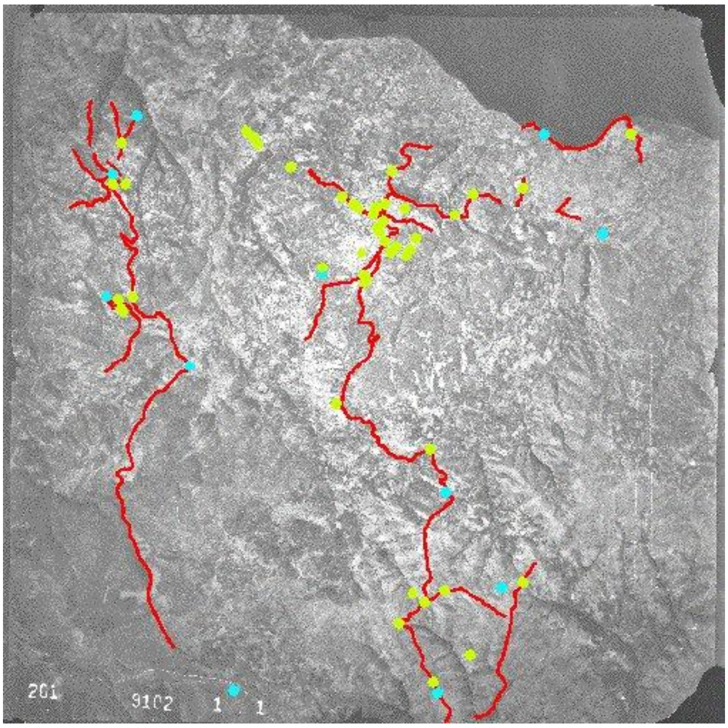

Figure 3: GCLFS (in red), CPs (in yellow) and GCPs (in cyan) on the historical photograph.

DISCUSSION AND CONCLUSIONS

In this paper the efficiency and workability of a method for the determination of georeferencing parameters of historical aerial photographs was developed using linear features (GCLFs) as Ground Control Information, without the a priori knowledge of the internal geometry of the camera. An application using real data was made; the accuracies of the calculated image coordinates of well identified CPs show the following:

- there is no significant difference in the results by using either the Collinearity Equations or the DLT with both GCLFs and GCPs. The identified differences are statistical insignificant as they are much smaller than the accuracy of the reference data (measured coordinates on a medium scale orthophoto). So, the DLT may be used as mathematical model of the transformation equations without any losses in the accuracy of the products; it has much simpler equations and it does not require the use of initial values of the unknown parameters.
- using GCLFs better accuracies are achieved than using GCPs. The differences are approximately 1 m (for the “interpolation-in-time” process) and 4 m (for the standard process). If the easiness in the determination of linear features not changed through the years instead of characteristic points is added to the above it may be derived that the use of GCLFs is preferable than the GCPs for the georeferencing of historical photographs. The GCLFs-based process is quite straightforward compared to the GCPs based process which strongly depends on the experience of the user, the available budget and time and the user's patience to identify (or even to guess) as many as possible GCPs and then to try out numerous combinations of GCPs and CPs until to reach an “acceptable” result, leaving ambiguities about the final result.

Based on these initial results, major issues of future research are considered to be:

- the extension of the transformation equations (Collinearity Equations and DLT) by introducing the parameters for the full calibration of the camera; the coordinates of the principle point (x_o, y_o) and the radial distortion (dr).
- the simultaneous application of the proposed method on more than one historical photographs so that the geometry of the solution will be strengthened through the intersection of homologous rays. In this way the correlation between certain parameters (for instance c and Z_o) is avoided.
- further comparison between the results of the models of Collinearity Equations and of DLT in various test fields. From the 11 parameters of the DLT, the parameters of the interior (c_x, c_y, x_o, y_o) and the exterior (X_o, Y_o, Z_o, ω, φ, κ) orientation may be calculated for each image so that a direct comparison of the results of the two transformation models will be possible.

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