Registration of very time-distant aerial images

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Objective

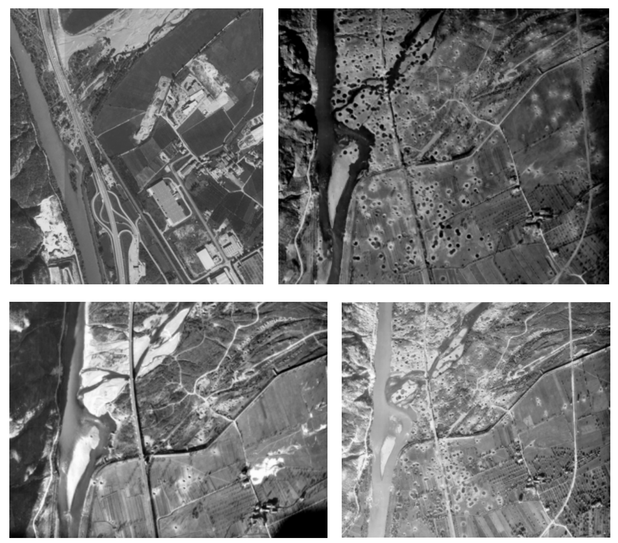
In this paper we address the alignment of historical and present-day aerial photographs.

Historical images refer to regions bombed during the second world war. In this regions the risk of unexploded bombs is still high, especially where the bombing were more frequent.

The alignment is used to fill-in an **unexploded bombs risk map**.

The task is challenging because:

- a lot of features in the historical images are changed or missing (and vice versa)
- in the historical images, bomb craters introduce large gray level variations so that it is difficult to extract features automatically.



Present-day image and historical images of the same area.

Overview

The method is based on the matching between corresponding features observed on a pair of images.

From the correspondences we obtain the homography that aligns correctly the image pair.

The main steps are: features extraction and homography estimation.

Feature Extraction

Lines are extracted by means of a variation of the Hough transform which integrates in the voting scheme the information about gradient direction.

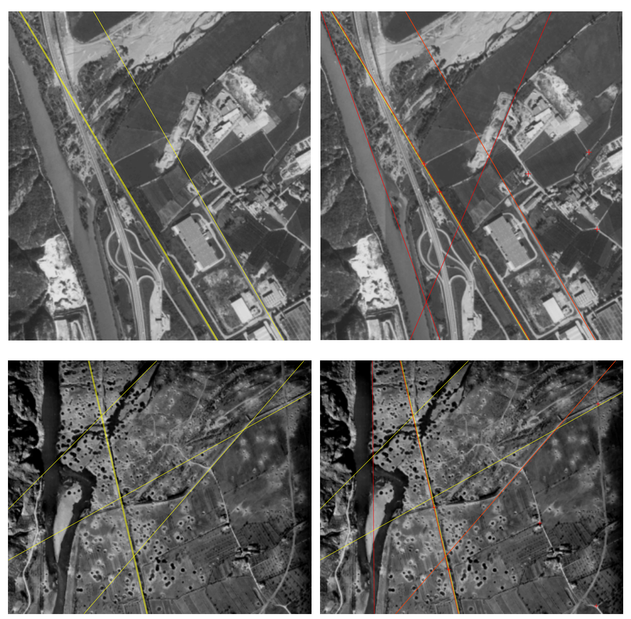
In this way we remove spurious lines caused by bomb crater edges accidentally aligned, but the lines that get automatically extracted are not enough to yield a good registration.

Especially in the historical images, roads and crossroads are less visible and they have a weak gradient. Moreover, bomb craters have strong gradient and they introduce spurious features.

User interaction is needed: he or she must validate the extracted lines and can introduce new lines or salient points.

Lines and points selected by the user get shifted toward

- the closest maximum in the Hough voting space
- the closest maximum in the response of the Harris&Stephens corner detector.



Automatic line extraction and features introduced by the user.

Homography Estimation

A *homography* is a non-singular linear transformation of the projective plane into itself. The most general homography is represented by a non-singular 3×3 matrix H:

$$m_i' = H \cdot m_i \tag{1}$$

where m_i' is the corresponding point of m_i.

Two images are related by a homography if the scene is planar or if the point of view does not change.

In our aerial images it is safe to assume that the scene is planar.

Four points, provided that no three of them are collinear, determine a unique homography.

Each point correspondence in the plane provides two equations in the unknown entries of H:

$$\begin{cases} x'(H_{3,1}x+H_{3,2}y+H_{3,3}) = H_{1,1}x+H_{1,2}y+H_{1,3} \\ y'(H_{3,1}x+H_{3,2}y+H_{3,3}) = H_{2,1}x+H_{2,2}y+H_{2,3} \end{cases} . \tag{2}$$

In the projective plane points and lines are dual elements: if corresponding points are related by Eq. (1), then corresponding lines are related by

$$l = (H)^T \cdot l' \tag{3}$$

Each line correspondence in the plane provides two equations in the unknown entries of H, analogous to Eq. (2), modulo some permutation of elements.

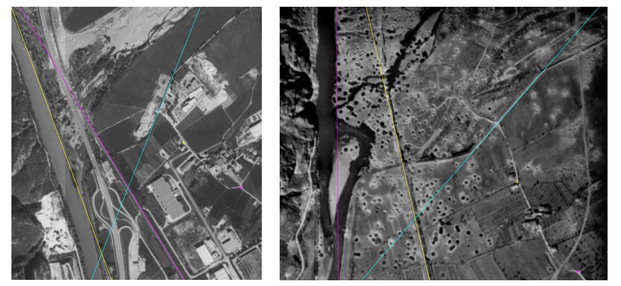
These equations can be rearranged in matrix form, obtaining:

$$\begin{pmatrix} \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ x_i & y_i & 1 & 0 & 0 & 0 & -x_i x_i' & -y_i x_i' \\ 0 & 0 & 0 & x_i & y_i & 1 & -x_i y_i' & -y_i y_i' \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ t_i' & 0 & -t_i t_i' & u_i' & 0 & -t_i u_i' & 1 & 0 \\ 0 & t_i' & -u_i t_i' & 0 & u_i' & -u_i u_i' & 0 & 1 \end{pmatrix} \begin{pmatrix} H_{1,1} \\ H_{1,2} \\ H_{1,3} \\ H_{2,1} \\ H_{2,2} \\ H_{2,3} \\ H_{3,1} \\ H_{3,2} \end{pmatrix} = \begin{pmatrix} \dots \\ x_i' \\ y_i' \\ \dots \\ t_i \\ u_i \end{pmatrix}$$

Since there are usuallly more than four elements (points or lines), compute a least-squares solution for H.

In our approach, homography and features matching are computed at the same time using the RANSAC algorithm.

- All the possible matches between the two feature sets, left and right, are considered and for each of them we estimate the best homography.
- Given a set of feature pairs we consider all the subsets composed by four pairs (the minimum number needed to specify a homography).
- We estimate the homography and apply it to the image.
- Every pair votes this homography if the residual $r_i = Hm_i - m_i'$ is under a given threshold T.
- The homography that receives the maximum number of votes is the winner.



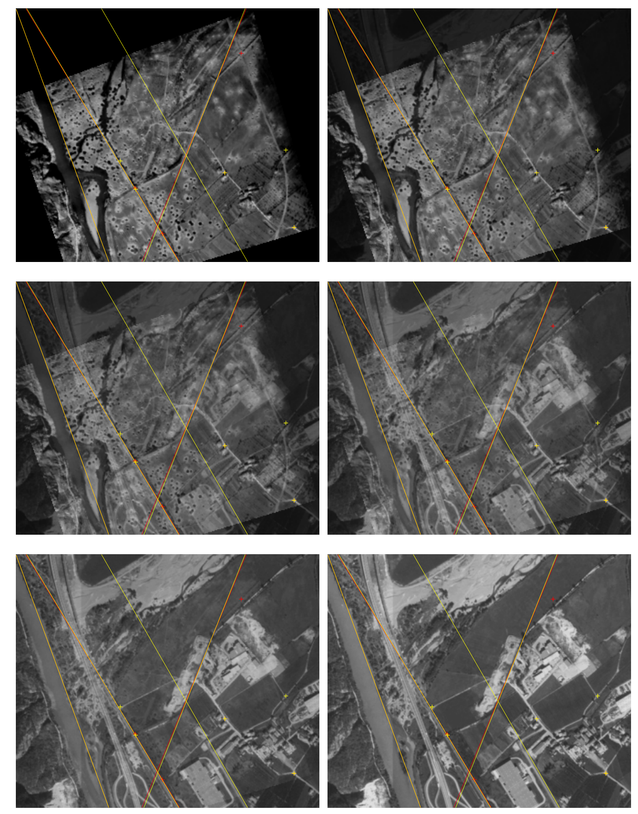
Extracted correspondences between present-day image and historical image.

Results

We tested our method on a set of historical and present-day images. Salient features, observable in all the images, are the river, the railway and the road from the upper-right side to the center of the region.

Images	Average residuals (pixel)
historical image 1	$6.0027 \cdot 10^{-7}$
historical image 2	$4.3844 \cdot 10^{-9}$
historical image 3	$2.8086 \cdot 10^{-10}$

Average residual distances between corresponding points.



Alignment between present-day image and historical image.
Images show the progressive blending of the historical photograph into the present-day one.

Conclusions

The background application is the assessment of the risk from unexploded air-dropped bombs in a given geographic area.

The approach is based on the estimation of the best homography that aligns corresponding lines and points.

Features are extracted with minimal user intervention and put in correspondence automatically using the RANSAC algorithm.

The complementary use of both automatic and user-entered information gives good results, in terms of accuracy and speed.

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