

# REGISTRATION OF VERY TIME-DISTANT AERIAL IMAGES

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## ABSTRACT

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 required 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). Moreover, in the historical images, bomb craters introduce large gray level variations so that it is difficult to extract features automatically. This work propose a semi-automatic application for images alignment in order to improve the accuracy and speed up alignment process.

## 1. INTRODUCTION

During the second World War, RAF and USAF released more than a million bombs over Italy. About a 10% remained unexploded. The risk of unexploded bombs is still high, especially in the regions in which the bombing were more frequent. This work is related to the UXB project [1] whose final goal is to fill in the unexploded bombs risk map. The advantages of having such a map are evident: it allows the optimization of defusing operations and a better planning of urban development. Aerial photographs taken by RAF reconnaissance airplanes just after the bombing and mission records are available together with present-day georeferenced photographs [2]. The historical data are analyzed to produce a risk assessment, including estimates of the number or tonnage of bombs dropped on the study area and the number and types of unexploded bombs [1]. In order to plot bomb impacts onto modern maps (i.e., georeferencing them) to provide a hazard zoning of the territory, the historical images needs to be *registered* with the present-day ones. This is the problem we address in this paper.

Given two images of the same scene taken from different viewpoints and possibly different sensors, image registration is the process of determining the transformation that most nearly maps one image to another [3]. This is a heavily studied problem in the field of image processing (e.g.

remote sensing, medical imaging, multisensory image integration, etc. [4, 3, 5, 6]). Usually, image registration problem is solved through the extraction and matching of a set of *feature points* (e.g. control points, corners, line segments, etc.) which determine a suitable transformation that aligns the images [7, 8, 9].

We use a full projective model, therefore registration reduces to computing the homography  $H$  that aligns the two images [10] starting from a given set of corresponding features (e.g., streets, railways, crossroads, houses, etc.). The problem is that a lot of features in the historical images are now changed or missing (and vice versa). Bomb craters introduce large gray level variations so that it is difficult to extract features automatically. For this reason, we implemented a semi-automatic method that requires the user to validate a set features automatically extracted and possibly add new ones. Matching is performed automatically using RANSAC algorithm [11].

This semi-automatic approach has a considerable advantage over a pure interactive method, because a user can introduce errors, losing alignment accuracy. Moreover a manual matching between corresponding features requires close attention and a lot of time.

The rest of the paper is organized as follows: in Section 2 we describe implemented application focusing on the *feature extraction* and *homography estimation*. In Section 3 we show results and their evaluation. Finally in Section 4 conclusion are drawn.

## 2. PROPOSED METHOD

In this paper we propose a method to align a pair of images basing on the matching between corresponding features. In order to exploit all the available information we use corresponding points (buildings, crossroad, etc.) and corresponding lines (roads, railway, side of the river, etc.). From the correspondences we obtain the homography that aligns correctly the image pair. The main steps of our method are: features extraction and homography estimation.

## 2.1. Feature Extraction

Lines are extracted by means of a variation of the Hough transform [12, 13] which integrates in the voting scheme the information about gradient direction. For each edge point the highest score is given to the line perpendicular to the gradient direction. In this way we remove spurious lines caused by bomb crater edges accidentally aligned. However, 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. The user interface (written in MATLAB) allows to adjust these lines and points by shifting lines to the closest maximum in the Hough voting space and by shifting points to the closest maximum in the response of a corner detector [14].

## 2.2. Homography Estimation

A *homography* (or *collineation*) is a non-singular linear transformation of the projective plane [15] into itself. The most general homography is represented by a non-singular  $3 \times 3$  matrix  $H$ :

$$m'_i = H \cdot m_i \quad (1)$$

where  $m'_i$  is the corresponding point of  $m_i$ . Points are expressed in homogeneous coordinates, that is, 2-D points in the image plane are denoted as  $m = (x, y, 1)$  with  $(x, y)$  being the corresponding Cartesian coordinates.

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 we can suppose that the scene is planar.

Four points, provided that no three of them are collinear, determine a unique homography. Indeed, eight independent parameters are required to define the homography. Each point correspondence in the plane provides two equations in the unknown entries of  $H$ :

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

It is then necessary to find at least four point correspondences to define the transformation matrix uniquely, up to a scale factor.

In the projective plane points and lines are dual elements. Indeed, the line  $ax + by + c = 0$  is defined by the triple  $l = (a/c, b/c, 1)^T = (t, u, 1)^T$ . If corresponding points are related by Eq. (1), then corresponding lines are related by

$$l' = (H^{-1})^T \cdot l \quad (3)$$

or, switching left with right

$$l = (H)^T \cdot l' \quad (4)$$

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:

$$\begin{pmatrix} \dots & \dots \\ x_i & y_i & 1 & 0 & 0 & 0 & -x_i x'_i & -y_i x'_i \\ 0 & 0 & 0 & x_i & y_i & 1 & -x_i y'_i & -y_i y'_i \\ \dots & \dots \\ t'_i & 0 & -t'_i t'_i & u'_i & 0 & -t'_i u'_i & 1 & 0 \\ 0 & t'_i & -u'_i t'_i & 0 & u'_i & -u'_i u'_i & 0 & 1 \end{pmatrix} \begin{pmatrix} H_{1,1} \\ H_{1,2} \\ H_{1,3} \\ H_{2,1} \\ H_{2,2} \\ H_{2,3} \\ H_{3,1} \\ H_{3,2} \end{pmatrix} = \begin{pmatrix} \dots \\ x'_i \\ y'_i \\ \dots \\ t'_i \\ u'_i \end{pmatrix} \quad (5)$$

If there are more than four elements (points or lines), then we have more equations than unknowns, and, in general, only a least-squares solution for  $H$  can be found (e.g. using SVD [16]).

In our approach, homography and features matching are computed at the same time using the RANSAC algorithm [11]. 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 subset 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.

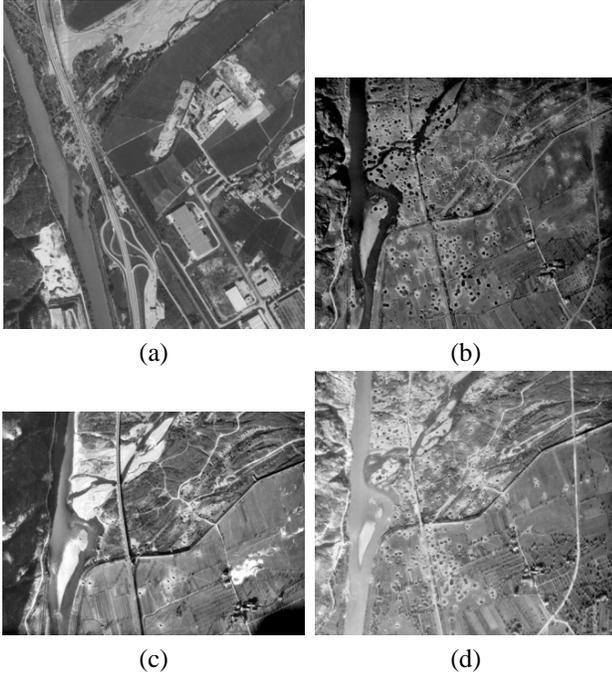
## 3. RESULTS

We tested our method on a set of historical and present-day images shown in Figure 1. 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. There are also different crossroads but is not clear which corresponds to which. In the present-day image new features appear (highway, buildings, roads). Moreover, in the historical images the craters introduce many spurious points.

Lines are automatically extracted and the user validate them and/or introduce new interesting lines and points (Figure 2 and 3).

RANSAC computes automatically correspondences and the homography. Using present-day image and the historical image, RANSAC found three corresponding lines (the river, railway and a road) and two corresponding points (crossroads in the bottom right side of the region) as shown in Figure 4. The estimated homography is applied to the historical image and Figure 5 shows the resulting alignment.

Table 1 shows the average residual distances between corresponding points.



**Fig. 1.** Present-day image (a) and historical images (b,c,d) of the same area.

Images	Average residuals (pixel)
historical image (b)	$6.0027 \cdot 10^{-7}$
historical image (c)	$4.3844 \cdot 10^{-9}$
historical image (d)	$2.8086 \cdot 10^{-10}$

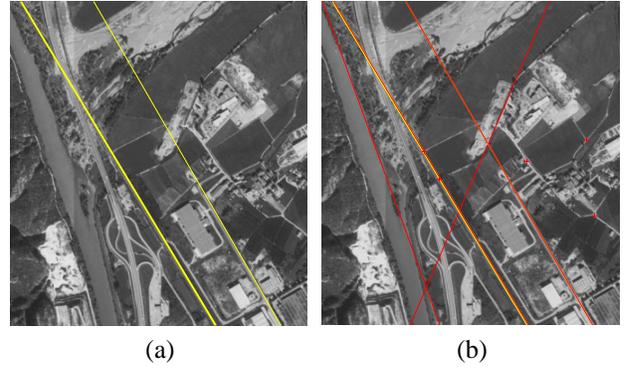
**Table 1.** Mean of residuals for each alignment between present-day image and historical image

#### 4. CONCLUSIONS

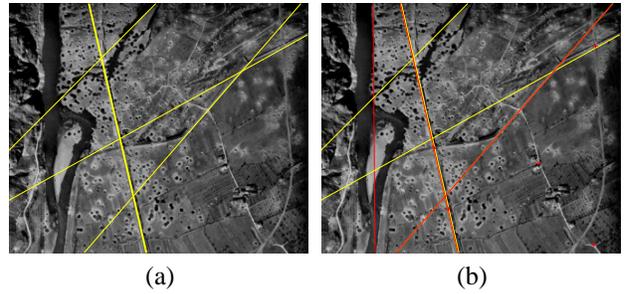
In this paper we proposed a method to align historical images to present-day images of the same region. The background application is the assessment of the risk from unexploded air-dropped bombs in a given geographic area. The approach is based on the estimation of the best homography that aligns corresponding features (lines and points) which 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. Future work will address non-flat regions by taking the digital elevation map (DEM) into account.

#### Acknowledgments

The images used in this work are part of the data base of the UXB Trentino project (ITC/IRST and Autonomous Province



**Fig. 2.** Automatic line extraction (a) and features introduced by the user (b).

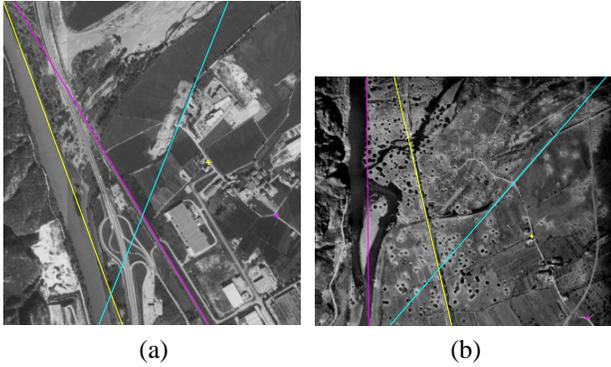


**Fig. 3.** Automatic line extraction (a) and features introduced by the user (b).

of Trento). In particular the historical images come from the National Archives, Maryland, USA.

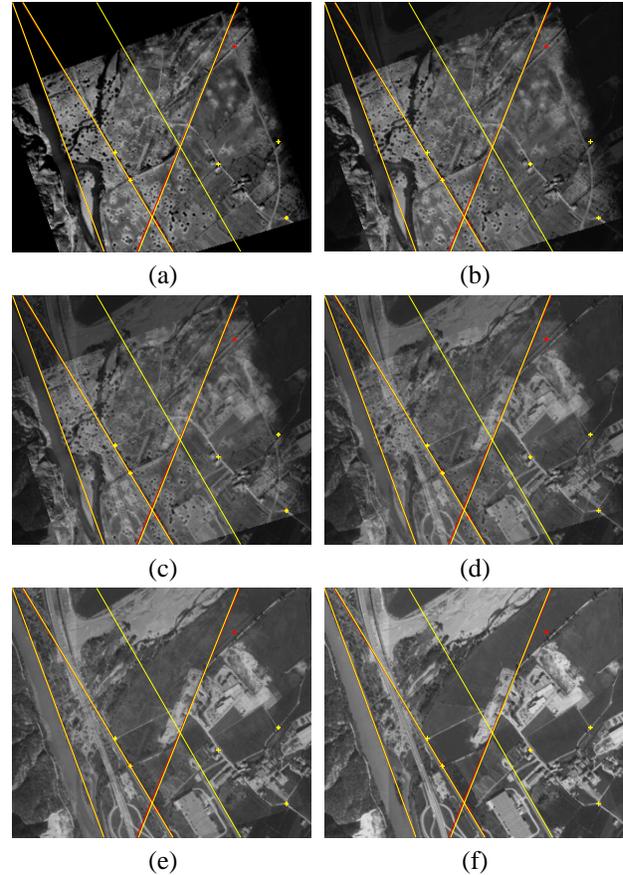
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**Fig. 4.** Extracted correspondences between present-day image and historical image.

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**Fig. 5.** Alignment between present-day image and historical image. Images show the progressive blending of the historical photograph into the present-day one.

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