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Image matching for historical maps comparison

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Summary

In cartographic heritage we suddenly find maps of the same mapmaker and of the same area, published in different years, or new editions due to integration of cartographic, such us in national cartographic series. These maps have the same projective system and the same cut, but they present very small differences.

The manual comparison can be very difficult and with uncertain results, because it's easy to leave some particulars out. It is necessary to find an automatic procedure to compare these maps and a solution can be given by digital maps comparison.

In the last years our experience in cartographic data processing was opted for find new tools for digital comparison and today solution is given by a new software, ACM (Automatic Correlation Map), which finds areas that are candidate to contain differences between two maps. ACM is based on image matching, a key component in almost any image analysis process.

Introduction

As can be easily understood by the last literature, maps comparison is an efficient method to extract information from different nature maps, such as historical or actual ones. Very often, we have the necessity to consider maps with the same geographical content, such as subsequence editions of IGM sheets, or new copy of the same mapmaker, and to find differences. The main question is how to compare maps without neglecting details, as it can happen if the process is done manually.

Figure 1. IGM series of 1:25000 "tavoletta".

In the past, our research team presented some solutions, such as the definition of new software, 2W, based on plane transformations, particularly on warping algorithm, to fix correspondences between two maps without operate on the semantic content of maps (Guerra, 1998; Balletti, 2000).

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2W software was an answer to the main problem with plane transformation procedure that is giving a new geometric support to a map in order to assign it a new metric nature (the mapping of one map onto another), often radically modifies the original map. The implemented software for this purpose was inspired by the fact that the screen can be organised into two windows. In these, on the left window, the reference cartography is visualised and on the right, the transformed one. The methods of functioning are quite commonplace: by identifying a point on one of the two maps, the program calculates the position on the other and highlights this by centring the two windows on homologous points. The centre of the two windows is always on two corresponding points. This involves a software which implements the algorithms of local transformation, based on points or lines, borrowed from the morphing techniques of computer graphics and properly adapted to cartography.

Figure 2. 2W software screencaptures

A new purpose comes from a settled technique, *image matching*, that is a crucial automatic processing to a wild range of application, particularly in photogrammetry, for stereoscopic homologous points recognition. The procedure principle is to find similarities, neglecting differences.

For the cartographic application it was design a new software, *ACM (Automatic Correlation Map)* that exploits image matching to find areas which are candidates to contain map differences.

Matching methods

Matching methods can be: area based, feature based or symbolic.

Area-based methods, perform the image match by a numerical comparison of digital numbers in small sub-arrays from each images. This approach is commonly used in softcopy photogrammetric system.

Feature-based methods are more complicated and involve extraction of features, which are comprised of edges at different scale, with subsequent comparison based on feature characteristic such as size and shape. Feature-based image matching requires techniques from the realm of artificial intelligence in computer science.
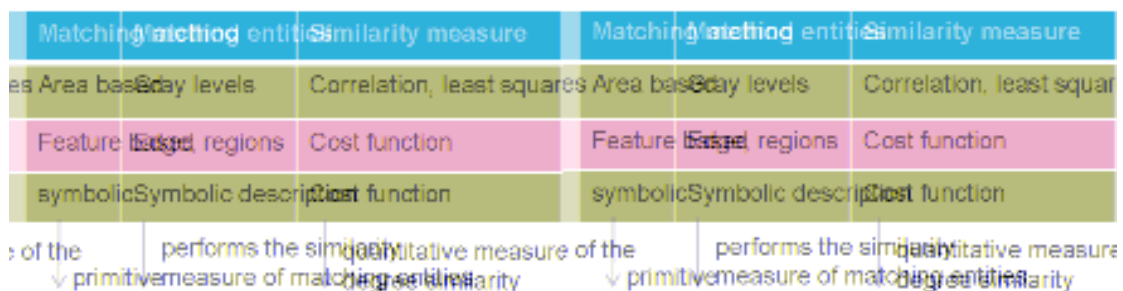

Figure 3. Relationship between matching methods and matching entities.

Symbolic methods is an hybrid solution that involve some combination of the first two approaches: after the features (edges) have been located in a preprocessing step, they are matching by area based methods.

All three approaches have particular advantages in different application field.

In order to analyze maps whit small differences the most useful method is the area-based.

Area based principle is to compare the gray level distribution of a small sub-image, called image patch, with its counterpart in the other image. Fig.4 illustrates the concept and introduces a frequently used terminology, such as *template* that is the image patch, which usually remains in a fixed position in one of the image; *search windows* refers to the search space within which image patches, or matching window, are compared with the template.
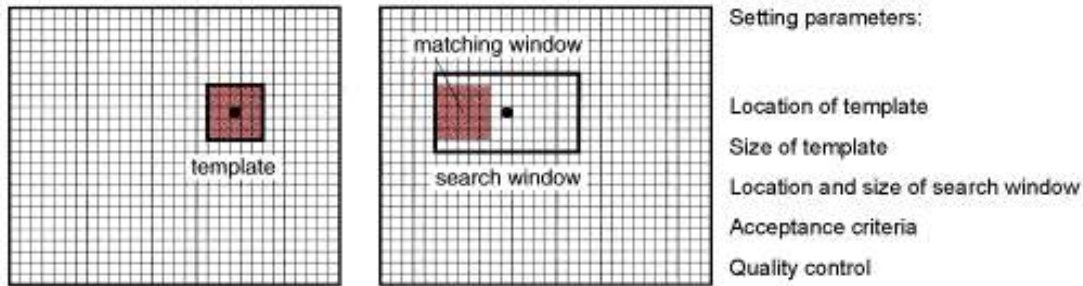

Figure 4. Area based matching concepts.

The comparison is performed with different similarity measure criteria: the two best known criteria for the comparison of the areas in the area-based method are *cross-correlation* and *least squares matching*.

Comparison criteria

In cross-correlation area based method, a statistical comparison is computed from digital numbers taken from same-size sub-arrays in the two image. The numbers are the gray levels of the image pixel. A correlation coefficient is computed by the following equation, using digital numbers from sub-arrays A and B.

$$c = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \left[\left(A_{ij} - \bar{A} \right) \left(B_{ij} - \bar{B} \right) \right]}{\sqrt{\left[\sum_{i=1}^{m} \sum_{j=1}^{n} \left(A_{ij} - \bar{A} \right)^2 \right] \left[\sum_{i=1}^{m} \sum_{j=1}^{n} \left(B_{ij} - \bar{B} \right)^2 \right]}}$$

In the equation c is the correlation coefficient; m e n are numbers of rows and columns in the sub-arrays; A_{ij} is the grey level from sub-array A at row i, column j; $\bar{A}$ is the average of all the grey in A; B_{ij} is the grey from sub-array B at position i, j; and $\bar{B}$ is the average of all the grey in B.

The normalized cross-correlation coefficient r assumes values in the range from -1 to +1 , with +1 indicating perfect correlation (exact match). A coefficient of -1 indicates an inverse correlation, such in the case with a positive and a negative of the same image. Coefficient value near zero indicate non-match, and could result from comparison of any two set of random numbers. Generally a threshold value, such 0,7, is chosen and if the correlation coefficient exceeded that value, the sub-arrays are assumed to match.
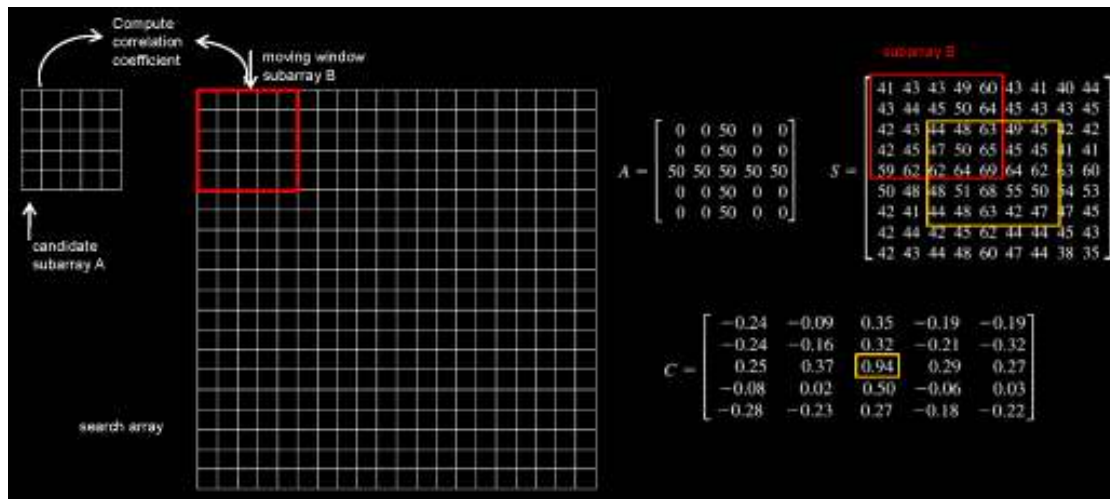
Figure 5. In this example the candidate array A is an ideal template for a fiducial cross, and the S search array is a portion of a digital image containing the cross. Maximum correlation coefficient, 0.94, occurs at row 3, column 3 of the C array. This value is computed when the moving window is in the position of the yellow square.

Digital image matching by correlation can be performed in the following manner. A candidate sub-array, called *template*, form the image 1 is chosen, and a search will be performed for its corresponding sub-array in the image 2.

Since the exact position of the template in the image 2 is not initially known, a search array, or *matching window*, is selected with dimensions much larger than those of the template. Such as in moving window convolution, the template is moved in all the possible location in the matching window and the correlation coefficient is computed and stored in a correlation matrix C. After all coefficients have been calculated, the largest correlation value in C is tested and the corresponding location is considered to be matching (the yellow square in fig5). A second area based digital image matching method is the least squares matching, which is closely related to the correlation method, with the advantage of being able to obtain the match location to a fraction of a pixel.

The idea is to minimize the gray level differences between the template and the matching window.

Different implementations of least squares matching have been devised, with the following form being commonly used:

$$A(x,y) = h_0 + h_1 B(x',y')$$
$$x' = a_0 + a_1 x + a_2 y$$
$$y' = b_0 + b_1 x + b_2 y$$
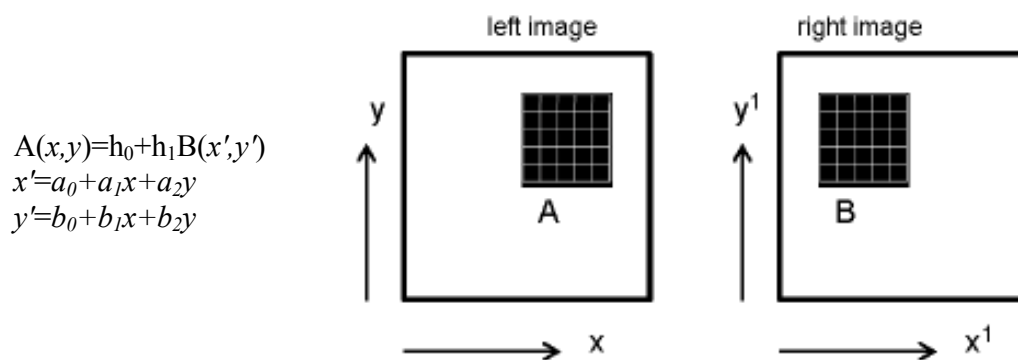
Analytically, in the first equation, $A(x,y)$ is the digital number from the candidate sub-array of the left image at position x,y; $B(x',y')$ is the digital value from a sub-array in the matching window of the right image at position x',y'; h_0 is a radiometric shift (a brightness difference) and h_1 is a radiometric scale (a contrast difference). the other two equations specify an affine transformation between corresponding pixels of the two images.

Due to maps characteristics (maps with the same system of reference, then with the same geometry), it's not necessary a geometrical transformation so cross correlation was chosen for the homologous point recognition in *ACM*.

ACM functionalities

Once the two images are loaded, the template size and the search window size have to be set. Then the computation starts by defining the scanning step (every how many pixel the template is fixed) in the first image.
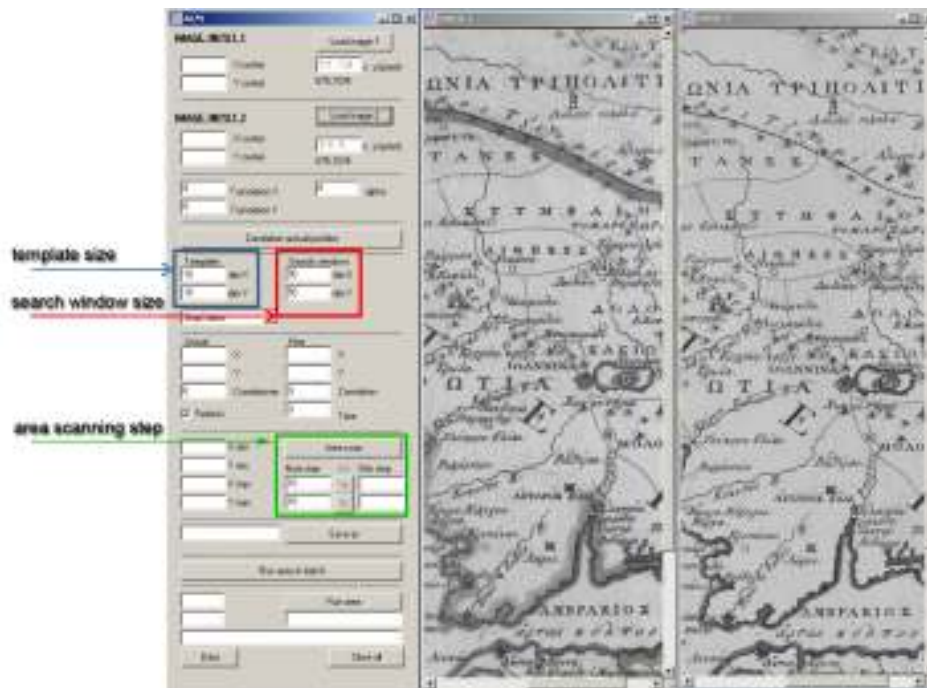

Figure 7. ACM input setting.

All the correlation factor are stored and they can be visualized in a sheet containing for each pixel its id point, its left and right image coordinates and its correlation factor.

If the correlation factor is near to 1, the two images in that point are the same; if it's less than 0.6, points are candidate be to different, so it is necessary to verify manually the difference by using the visiting function, such as in figure 8.

The third possibility is given by a negative value of correlation: it means that one image, in that point, is radiometrically the negative of the other (fig 10).

Briefly, the implemented algorithm for maps comparison performs the following steps:

- selection of a set of points regularly spaced in the first image;
- homologous points search in the second image (by cross-correlation matching) and correlation factors storage;
- realization of a map of the calculated correlation values to be overlapped to the first image.

The results of this first experimentation, which was done on several maps such as two different edition of Rigas Charta (Livieratos, 2008), demonstrate that wide parts of concerned maps are certainly recognized such as equal areas, so they are cut off from the manual control, bringing a considerable operating advantage to cartographic analyses.
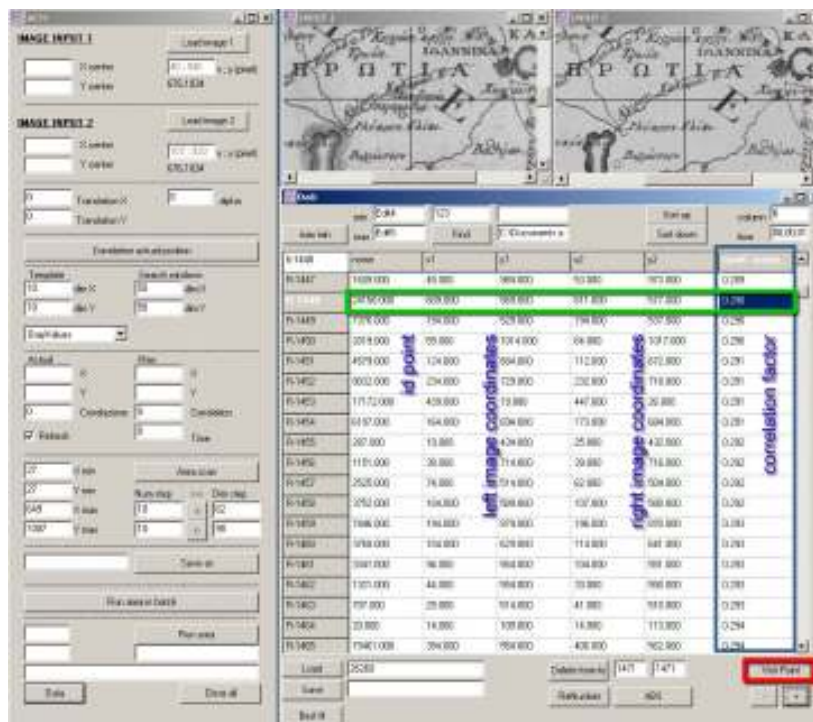
Figure 8. Visualization of the correlation coefficient of each point. In the red square the visit point function.
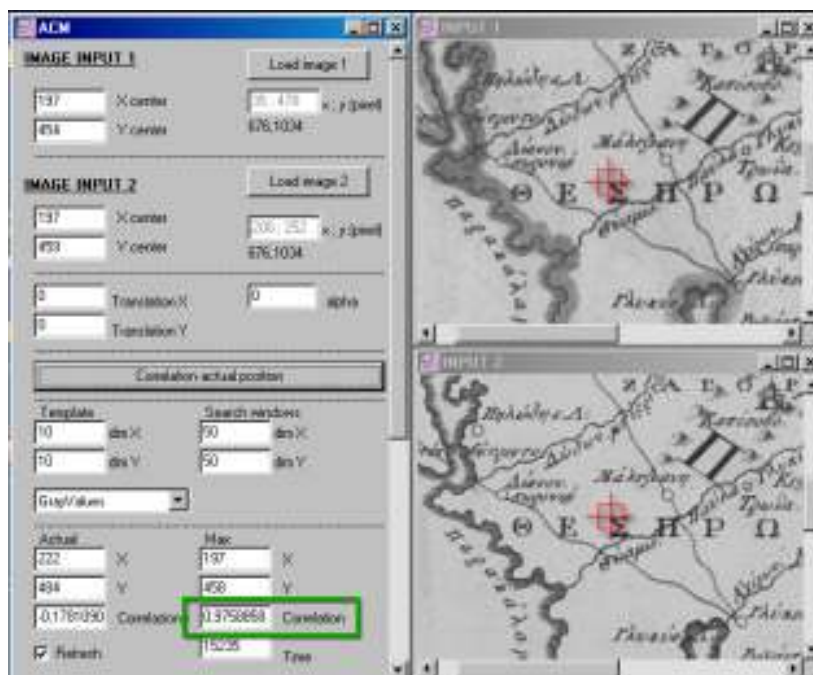

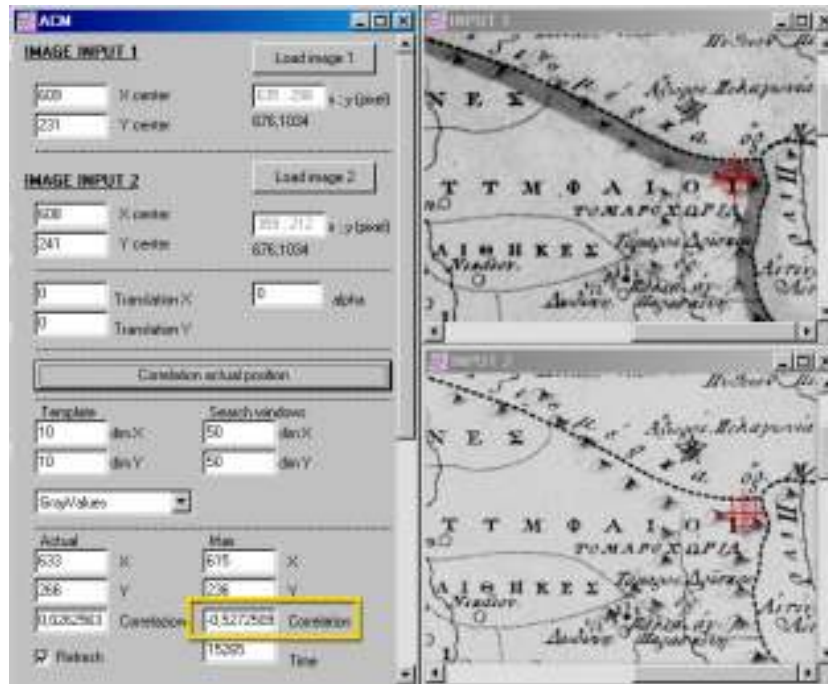Figure 9. An example of high correlation factor to locate equal area.

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Figure 10. An example of negative correlation factor to locate a zone of the second image
that can be considered as the negative of the first one.

References

Livieratos E. (2008), On the cartography of Rigas Charta, *e-perimetron*, Vol.3, no.3, 120-145.

Balletti C., Guerra F., Monti C. (2000), *Analytical methods and new technologies for geometrical analysis and georeferenced visualisation of historical maps,* in ISPRS, The International Archives of Photogrammetry and Remote Sensing, Volume XXXII, Part 6W8/1, ISPRS WG VI/3 e WG IV/3 , ISSN 0256-1840, pp.1-7.

Balletti C., Guerra F., Monti C., Livieratos E., Boutoura C. (1999), *Studi ed elaborazioni informatiche e infografiche sulla veduta prospettica di de'Barbari,* in *A volo d'uccello. Jacopo de' Barbari e le rappresentazioni di città nell'Europa del Rinascimento*, Arsenale Editrice,Venezia, , ISBN 88-7743-261-6, pp. 92-100.

Guerra F. (1998), *Local geometric transformation of images for the restoration of cartography,* in proceeding of the 5th Hellenic Cartographic Conference "Large Scale Cartography: City Maps", XEEE-HCS, pp.151-175.

Wolf P., DeWitt B., (2000) *Elements of digital photogrammetry*, McGraw Hill. ISBN 0072924543

Shenk T. (1999), *Elements of digital photogrammetry*, TerraScience, Laurelville.