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A methodology for image matching of historical maps

Keywords: Historic Maps, Modern Maps, Image Processing, Transformation, Correlation

Summary

Generally, maps are subject to spatial changes due to several factors. Some of these are older land surveying and mapmaking techniques, human endeavor (unwitting errors, misrepresentation, bias, or outright fraud), switching to newer and more accurate spheroids or projections, and intentional spatial changes for political or security purposes. This problem arises when we combine information from existing paper maps with data from Global Positioning System (GPS) readings or with scanned maps or satellite imagery. Maps from different sources, from different types and different years (historical maps) do often miss the needed transformation parameters. The correct integration of these pieces of information (e.g. GIS data) requires a correct matching of the data as far as geographic location is concerned. This research aims to find an analytical objective methodology by which historical maps can be examined against modern ones to detect and locate the spatial changes using digital raster image processing techniques.

Introduction

An enormous amount of historical maps was produced during the last centuries and became out of date over time. Such historical maps can provide valuable information for different disciplines and can be useful for surveyors, geographers, historians and others interested in researching the background of an area. A number of mapping organizations worldwide, such as the Federal Geographic Data Committee FGDC, exert continuous efforts to promote the awareness of the historical dimension to geospatial data and to facilitate maintaining and preserving historically valuable geospatial data and making it available for future generations (Abrams 2005). Historical maps provide much information about what was known in times past, as well as the philosophy and cultural basis of the map, which were often much different from modern cartography (Boutoura and Livieratos 2006). Nowadays, many aspects of cartography have been changed extremely due to the fast technological development into a computerized society (Benavides and Koster 2006). Modern digital computational and graphic technologies present the right tools to face the acquirement shortcomings of the past and massive computational labor (Jenny 2006). Thus, the comparison process of historical maps with modern data became easier. To enable such comparison, differences due to techniques used to produce maps are considered. This must result in a method that objectively describes how to interpret and compare features on historical maps with the same elements on reliable modern maps (Benavides and Koster 2006).

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Aim and Objectives

This research aims to provide a new objective approach that could be easily applied through a set of simple tools to compare old maps against modern maps, consequently obtaining results that bear statistical meaning in lieu of subjective and/or manual methods or pure visualization methods. To achieve this aim the following objectives are to be determined:

a) Developing a map similarity measure between historical and modern maps based on statistical correlation analysis.
b) Developing a digital tool to perform the comparison process in an automated way.

Previous Work

A lot of research has been carried out to evaluate and study the accuracy of historical maps. According to Jenny et al. (2007), the applications of accuracy analysis are twofold. An analysis may support or refute a hypothesis about technical aspects of map creation. For example, verification assumptions about the surveying methods and source maps used to compile the map or examine its underlying projection and geodetic reference. Alternatively, an analysis may indicate the geometric reliability of information extracted for historic research. However, this specific field of research is still rather rare in the overall literature of historic cartography (Boutoura and Livieratos 2006). Livieratos (2006) provides concise overviews of techniques developed for the graphical analysis of old maps. Boutoura and Livieratos (2006) explain the basic concepts and tools available for the comparison of early maps with modern counterparts using best fitting techniques through proper transformation of sets of points of the early maps into corresponding sets of points of the modern one. Geometrical analysis of georeferenced visualization of historical maps is reviewed in: Livieratos 2006; Balletti et al. 2000; Podobnikar 2007. Jenny (2006) and Jenny et al. (2007) outline the purpose and goals of an analysis of a historical map's planimetric accuracy and identify possible sources for geometric imprecision and also introduce MapAnalyst software as a digital tool for determining the planimetric accuracy of historical maps. Benavides and Koster (2006) identify the surviving landmarks on historical maps and conclude that well chosen reference points for the geo-rectification process will help in getting better knowledge on the technical reliability. Jessop (2006) and Rumsey and Williams (2002) illustrate the use of Geographic Information Systems (GIS) in integrating historical maps to analyze the spatial information they contain or to layer them with other spatial data. Balletti (2006) shows how the metrical content of historical maps can be recovered using GIS analyses, which lead to definitions of some efficient methodologies for their quantitative analysis. As maps are transformed to an image format while analyzing them, other useful areas of research regarding our interest such as image similarity, image matching, remotely sensing images, fingerprint recognition and face recognition of images are reviewed. A great deal of wide ranging research has been conducted on similarity and shape matching and much of this is covered in survey papers such as : Liu and Laganiere 2007; Mosrov 2005; Stentiford 2007. Some of the face recognition aspects are discussed in : Moghaddam and Pentland 1997; Moon and Philips 2001; Schwaniger et al. 2003.

The Developed Methodology

The discussion that follows illustrates the proposed ideas and steps of the work done to achieve the research goals. One of these goals is to develop a method by which decisions are made about

whether an historical map matches a modern one and to measure statistically the correspondence rate. This can be realized with a comparison process to determine whether they are similar.
Figure 1 shows the suggested general frame of work which illustrates the methodology tasks using digital image processing technique as a foundation. This methodology contains many major tasks. These tasks include map scanning, georeferencing, preprocessing, reading images, statistical correlation and evaluation. It is necessary to develop and test all different available algorithms in each task and to choose algorithms that suit this kind of application.

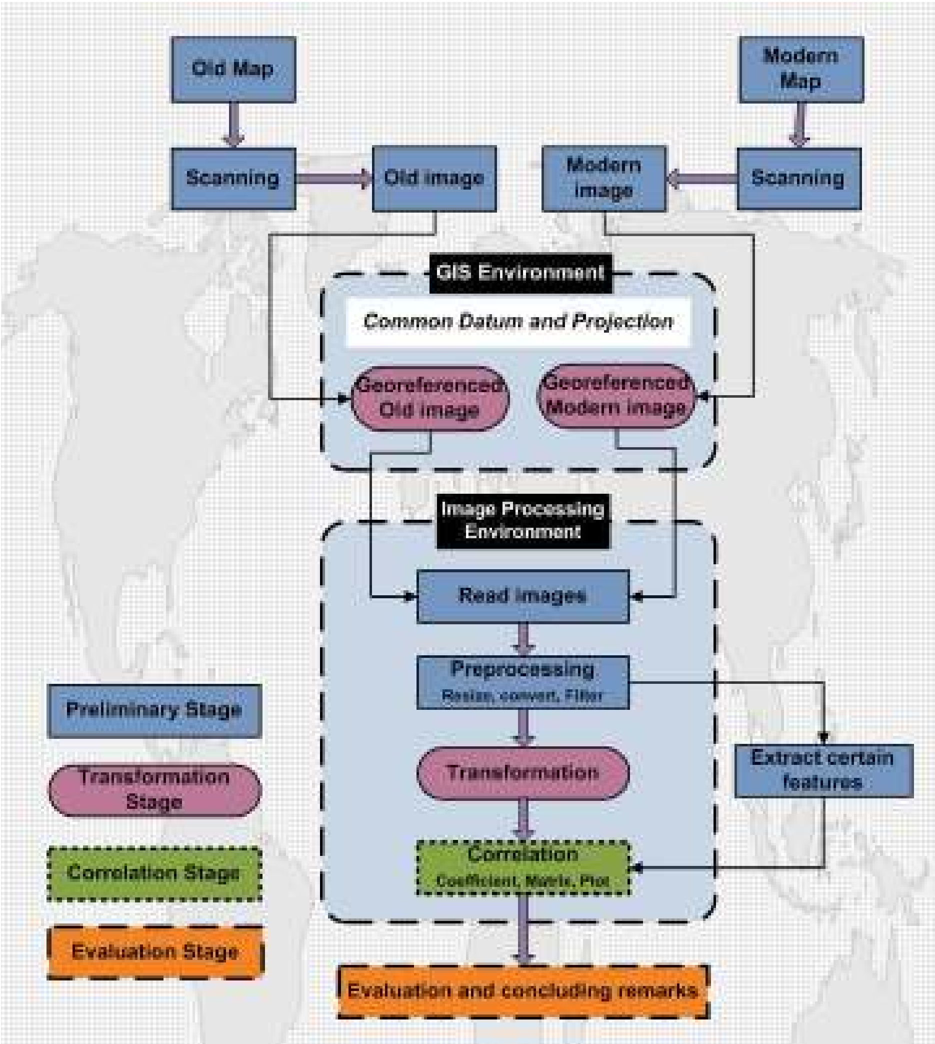

Figure 1. The proposed methodology framework.

The Developed Methodology Stages and Tasks

The proposed methodology presented in Figure 1 consists of four main stages and each stage has many related tasks. These stages include:

1. *The preliminary stage*: it involves scanning, storing, preprocessing, reading, resizing and other tasks that are necessary to start evaluating and analyzing images.
2. *The transformation stage*: it can be based on georegistering the compared images using GIS software to define their spatial coordinate reference and aligning them in a common coordinate system, and/or selecting a model to fit one image over the georefernced one.

3. *The correlation stage*: this stage includes obtaining matching measures such as a correlation coefficient between the images, correlation matrix and a correlation plot.
4. *The evaluation stage*: this stage is important and needed to consider conclusions and it involves evaluating filters, transformation and correlation through applying different case studies.

1. *The Preliminary Stage*

This stage is very important to prepare old and modern maps to be accurately analyzed and evaluated for reliability comparison and matching process. It involves scanning, digitizing, storing, preprocessing and other tasks that are necessary to start evaluating and analyzing map images. Figure 2 shows a schematic chart of the preliminary stage tasks.

Figure 2. The preliminary stage tasks.

a) Scanning task

Ordinarily, the first step in preparing a paper map for use is scanning it. The result is a digital image. A digital image is composed of *pixels* which can be thought of as small dots on the screen. For this purpose, it is best to capture map images at an acceptable resolution. High-resolution images show more pixels per inch (ppi) and therefore more detail. However, higher resolution images take up more memory such that a picture that is twice the resolution of its counterpart can require four times the memory. Tsioukas et al. (2006) describe a useful implementation technique of a photographic close range, non contact, scanning of antique maps. They also analyze the technical requirements and specifications that are important to enhance the photographic process for obtaining the most precise digital copies of these maps.

b) Digitizing Task

Digitizing is central in making a digital representation of geographical features, using raster or vector images, in a geographic information system, i.e., the creation of electronic maps, either from various geographical and satellite imaging (raster) or here, by digitizing our traditional paper maps (vector). This task is very important when we need to obtain certain features under consideration from both old and modern images and we need to find a similarity measure between them.

c) Reading task

This task represents an image as a matrix where every element has a value corresponding to how bright/dark the pixel at the corresponding position should be colored. For a grayscale image for example, it assigns an integer between 0 and 255 to represent the brightness of a pixel. The value 0 corresponds to black and 255 to white. Reading format should be in a grayscale. Other formats such as RGB are not suitable here since the difference of feature colors in both maps can affect the accuracy of matching results.

d) Resizing task

In order to compare image matrices, it is best to set each image matrix into a predefined dimension m × n (for example, 800 × 800) taking into consideration not to lose details in map images. Most image processing software can do this task. [

e) Filtering task

This task is necessary to improve the quality of both map images and it aims to prepare them to be processed accurately. It also facilitates the method of analysis. Preprocessing includes using filtering algorithms that can remove or even reduce images noise, smoothing, sharpening etc.

2. *The Transformation Stage*

When comparing two map images of different datums and or projections, a transformation process is strongly needed. GIS software can be used to project one map image, almost the old, to match the reference coordinate system of the other. Additionally, sets of data acquired by sampling the same scene or object features, at different times or from different perspectives, will be in different coordinate systems. Image registration also is the process of transforming the different sets of data into one coordinate system. Registration is necessary in order to be able to compare or integrate the data obtained from different measurements. That is, selected control points on a scan of a historical map image must be aligned with their actual location on a modern one. Maps containing a printed grid are simple to georeference as it is possible to click on an intersection of the grid and type the coordinates of that point. Else, prominent landmarks should be used. Minimum number of control points for each transformation type is shown in Table 1.

Transformation Type	Description	Minimum no. of CPs
Similarity	Straight lines remain straight and parallel are still parallel.	2
Affine	Shapes in the input image exhibit shearing.	3
Projective	The scene appears tilted. Lines remain straight.	4
Polynomial	Objects in the image are curved. The higher the order of the polynomial, the better the fit.	2^{nd} 6 3^{rd} 10 4^{th} 15
Piecewise linear	When parts of the image appear distorted differently	4

Table 1. Minimum number of control points (CP) required for each transformation type.

3. *The Correlation Stage*

Once both map images are geo-registered, a statistical correlation task can be established. The choice of an image similarity measure depends on the nature of the images. A basic image similarity-based method consists of a transformation model, which is applied to reference image coordinates to locate their corresponding coordinates in the target image space, an image similarity metric, which quantifies the degree of correspondence between features in both image spaces achieved by a given transformation, and an optimization algorithm, which tries to maximize image similarity by changing the transformation parameters. Common examples of image similarity measures include cross correlation, normalized mutual information, mean square difference and ratio image uniformity. A correlation algorithm is developed based on Normalized Cross Correlation formula to determine the correspondence between the compared map images. Normalized correlation is one of the methods used for template matching, a process used for finding incidences of a pattern or object within an image. For image-processing applications in which the brightness of the image and template can vary due to lighting and exposure conditions, the images can be first normalized. This is typically done at every step by subtracting the mean and dividing by the standard deviation. The cross-correlation of a template, $t(x, y)$ with an image $f(x, y)$ is:

$$r = \frac{1}{n-1}\sum_{x,y}\frac{(f(x,y) - f_m)(t(x,y) - t_m)}{\sigma_f \sigma_t}$$

Where:
r is the correlation coefficient and $-1 \leq r \leq 1$
n is the number of pixels in $f(x, y)$ and $t(x, y)$.
f_m and σ_f are the mean and standard deviation of image $f(x, y)$.
t_m and σ_t are the mean and standard deviation of image $t(x, y)$.

The correlation coefficient is 1 in the case of an increasing linear relationship, −1 in the case of a decreasing linear relationship, and some value between -1 and 1 in all other cases, indicating the degree of linear dependence between the variables. The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables. If the variables are independent, the correlation coefficient is 0. Correlation may be held for map images as a whole or some featured like borders can be extracted by choosing a suitable algorithm and then correlation may be started.
To determine locations of similarity and non similarity, correlation matrix of the two images with selecting a moving window size and correlation contour plot can be established. An algorithm is developed to divide each map image into a number of sub images with a predefined size of a moving window. This size can be input to as small as one pixel or greater in order to achieve any needed accuracy (see Fig. 3).
Next, the developed correlation algorithm can be used to correlate each sub image in the first map image with its equivalent in the second map image and store results in a correlation matrix. Figure 4 shows the procedure used to determine the correlation matrix. Each map image (a and b) is divided to subimages to a size equal to the division of each map size by a selected moving window size. Subimage a11 is correlated with b11 to determine the correlation coefficient r11 and a42 with b42 to get r42 and so on.

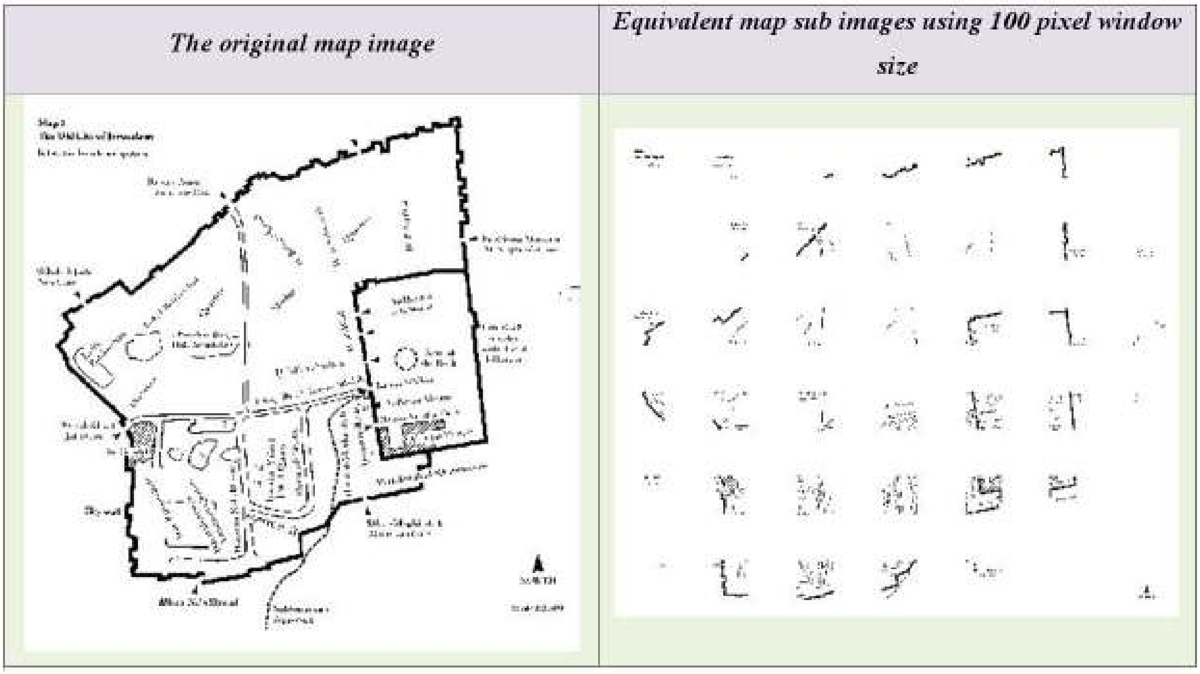

Figure 3. The original map image and its equivalent sub images.

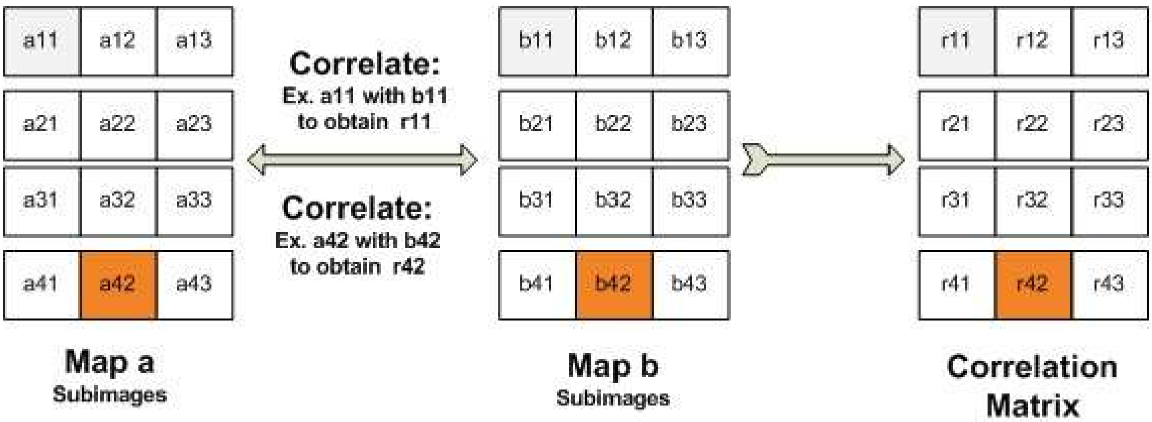

Figure 4. The process for determining the correlation matrix.

The determined correlation matrix is new in its concept and should be distinguished from that used in some statistics methods. Our developed correlation matrix may not be square and the diagonal also may not have values of ones. It is developed to locate places of distortion and measure statistically their corresponding correlation magnitudes.

Afterwards, another algorithm is designed to express the correlation matrix in a correlation contour plot form. This will enable us to easily visualize and locate the places of spatial change everywhere in the maps compared.

4. *The Evaluation Stage*

This stage is the responsibility of a specialist. He has to verify accuracy and reliable use of the data extracted from a historical map and to decide whether it is possible to combine or integrate it with other modern data. This matter depends on the matching results which can be achieved according to the previous correlation stage results (correlation coefficient, correlation matrix and correlation contour plot).

Guidelines for the interpretation of a correlation coefficient (Table 2) are given in resp. literature (see e.g. Wilcox, 2005). Cohen (1988) has observed, however, that all such criteria are in some ways arbitrary and should not be observed too strictly. The interpretation of a correlation coefficient depends on the context and purposes. A correlation of 0.9 may be very low if one is verifying a physical law using high-quality instruments, but may be regarded as very high in the social sciences where there may be a greater contribution from complicating factors.

In face image matching, a threshold of a 0.8 value is considered (Bruce and Young 1998). For map matching, 0.7 is considered according to Balletti and Guerra (2009).

Correlation	Negative	Positive
None	−0.09 to 0.0	0.0 to 0.09
Small	−0.3 to −0.1	0.1 to 0.3
Medium	−0.5 to −0.3	0.3 to 0.5
Large	−1.0 to −0.5	0.5 to 1.0

Table 2. Interpretation of a correlation coefficient

A Graphical User Interface Development

A Graphical User Interface (GUI) is strongly needed to execute most of the proposed methodology tasks and facilitate establishing the comparison between historical and modern maps and determining the statistical correlation in an automated way. Figure 5 shows a screenshot of the main front page of the developed GUI using MATLAB programming package, named "Map Correlation". The GUI has the capability to:

- Import and browse each map image into workspace.
- Filter each map image to reduce noise and consequently enhance comparison.
- Perform different types of transformation; similarity, affine, projective, polynomial etc.
- Save and export the transformed map in different image formats.
- Perform a transparent overlay of the transformed and reference maps (visual matching).
- Determine the correlation coefficient before and after transformation.
- Determine the correlation coefficient matrix and draw a correlation contour plot.

"Map Correlation" can browse different image formats such as bmp, jpg, jpeg, gif etc. Every image is automatically converted to a grayscale format. We can also apply many filters to enhance these images as median filtering, wiener and crisp filters by which noise can be reduced to minimum levels.

Before correlation, map images should be transformed into one coordinate system. It is preferred to transform a modern map to the coordinates of a historical one in order to keep details in the historical map. "Map Correlation" Interface can handle many transformation types. Some of these are affine, projective, linear conformal, piecewise linear, 2nd, 3rd and 4th order polynomials. User can select one of these types. Attention should be noticed to select the sufficient number of control points while choosing any type. Using "Map Correlation", Figure 6 shows the registration stage between two maps of Palestine; the overlay of the two maps is shown in Figure 7.

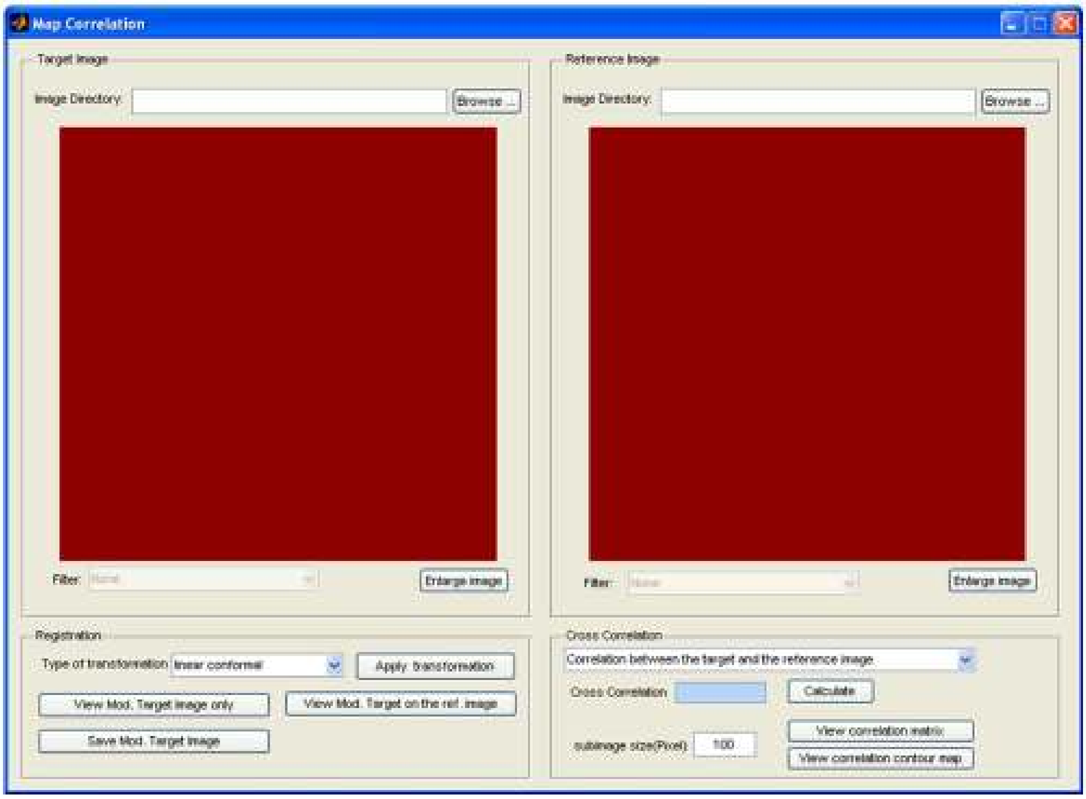

Figure 5. The main front page of "Map Correlation" GUI.

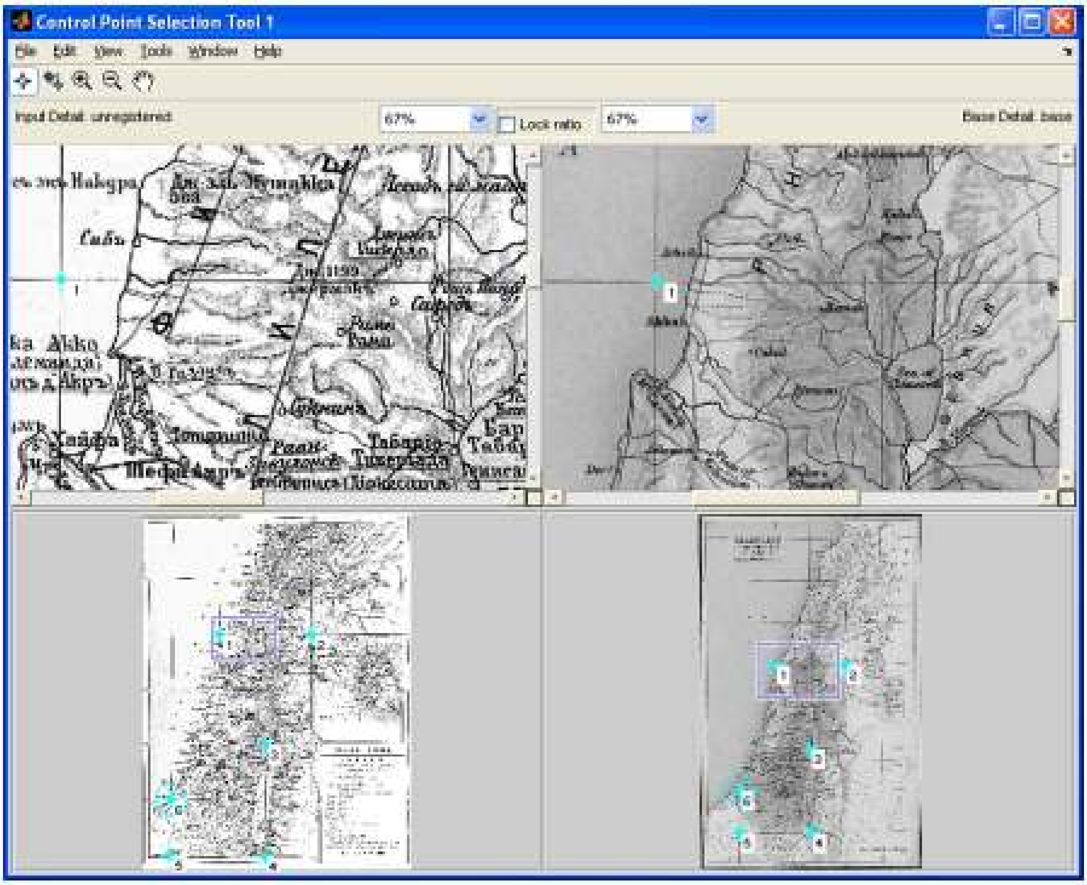

Figure 6. The registration stage between two maps of Palestine using affine transformation**.**

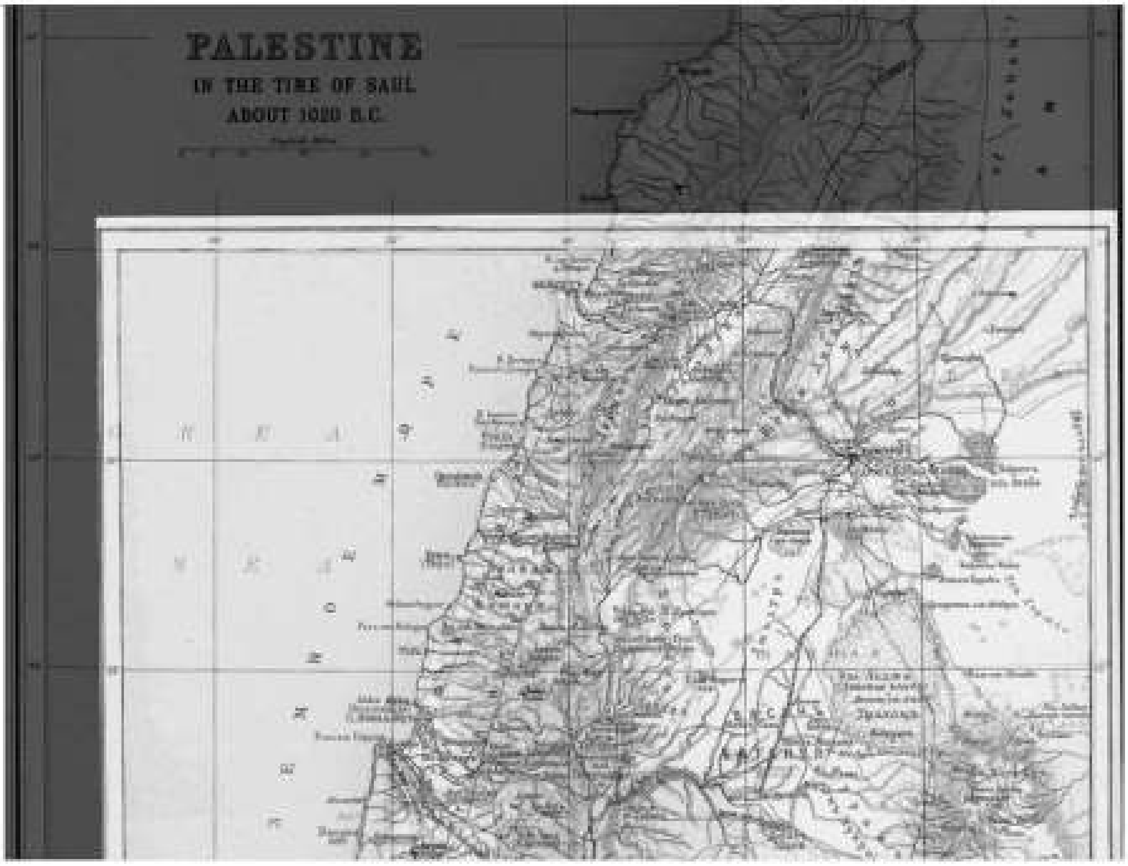

Figure 7. Overlaying the transformed and reference maps.

Analysis

Figure 8 shows the correlation coefficient, r, between map A (The Old City of Jerusalem) and some selected maps. Maps from A1 to A4 are derived from map A with gradually removing features from it. For example, A4 contains less detail than A3 and A2 less than A3, etc. Map B1 has some rotation compared with map A. This rotation is corrected in map B2 using "Map Correlation" interface. Maps C and D differ from map A where C represents the Gaza Strip, while D represents a Russian map of 1900, showing Palestine at that time.

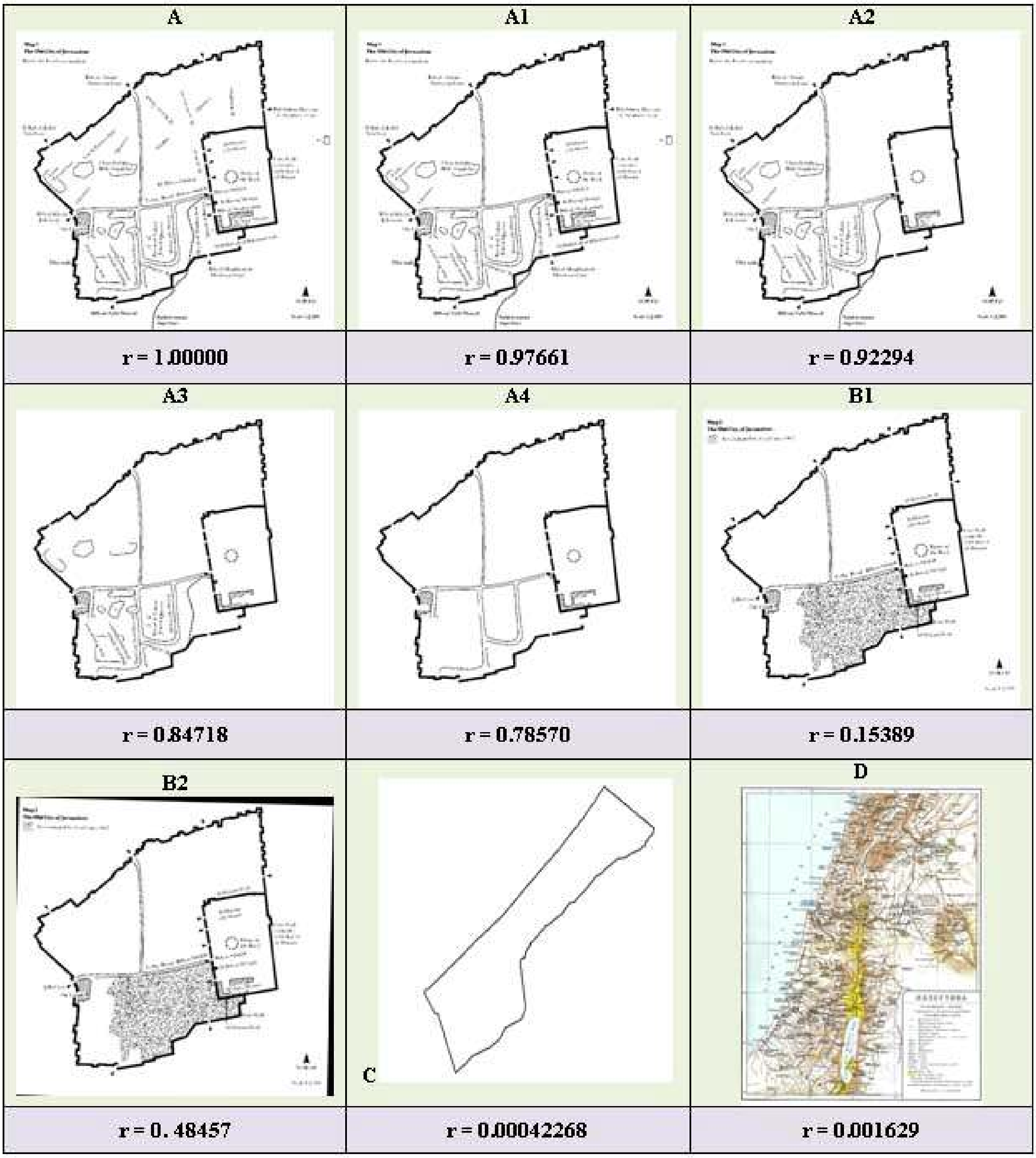

Figure 8. Correlation coefficients with map A using "Map Correlation" Interface.

As it can be seen from the comparison results, when comparing the map with its copy but gradually removing some details from the copy one, the correlation factor began to decrease gradually. The correlation coefficient between a map and its copy equals one and this means full similarity (e.g. A with A: r = 1.000) but when comparing a map with another almost different, the correlation coefficient approaches zero (e.g. A with C: r = 0.0004) and this means no similarity exists. These analyses indicate well performance and prove good reliability of our developed Interface. Figure 9 shows the correlation between a map of the Old City of Jerusalem and its copy after changing some detail in it, mainly at the upper right corner of the wall surrounding the city. This simulation aims to ensure that this tool can detect and accurately locate this distortion. The correlation coefficient is 0.9937 and this value agrees with the small variation in the maps. The correlation coefficient matrix also shows the distorted subimage area, using 80 pixel window size. It is as follows:

1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7726	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

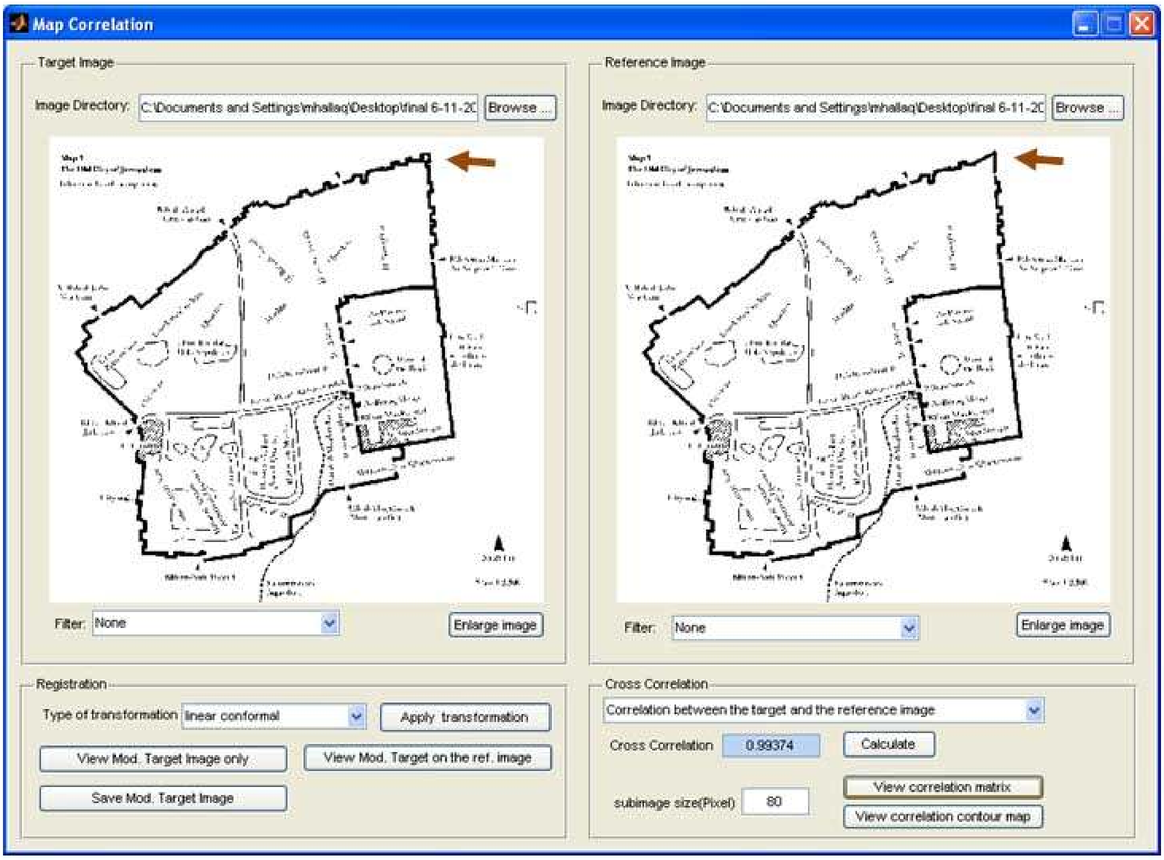

Figure 9. Correlation between two maps of the old city of Jerusalem.

The correlation contour plot using a 10 pixel window size, illustrated in Figure 10, also indicates the region at which distortion is introduced. For more precise detection of the involved distortion, less size can be used. Then, this contour plot can be easily overlaid in a digital transparent form over the tested map to show the magnitude and location of matching and non matching regions within it.

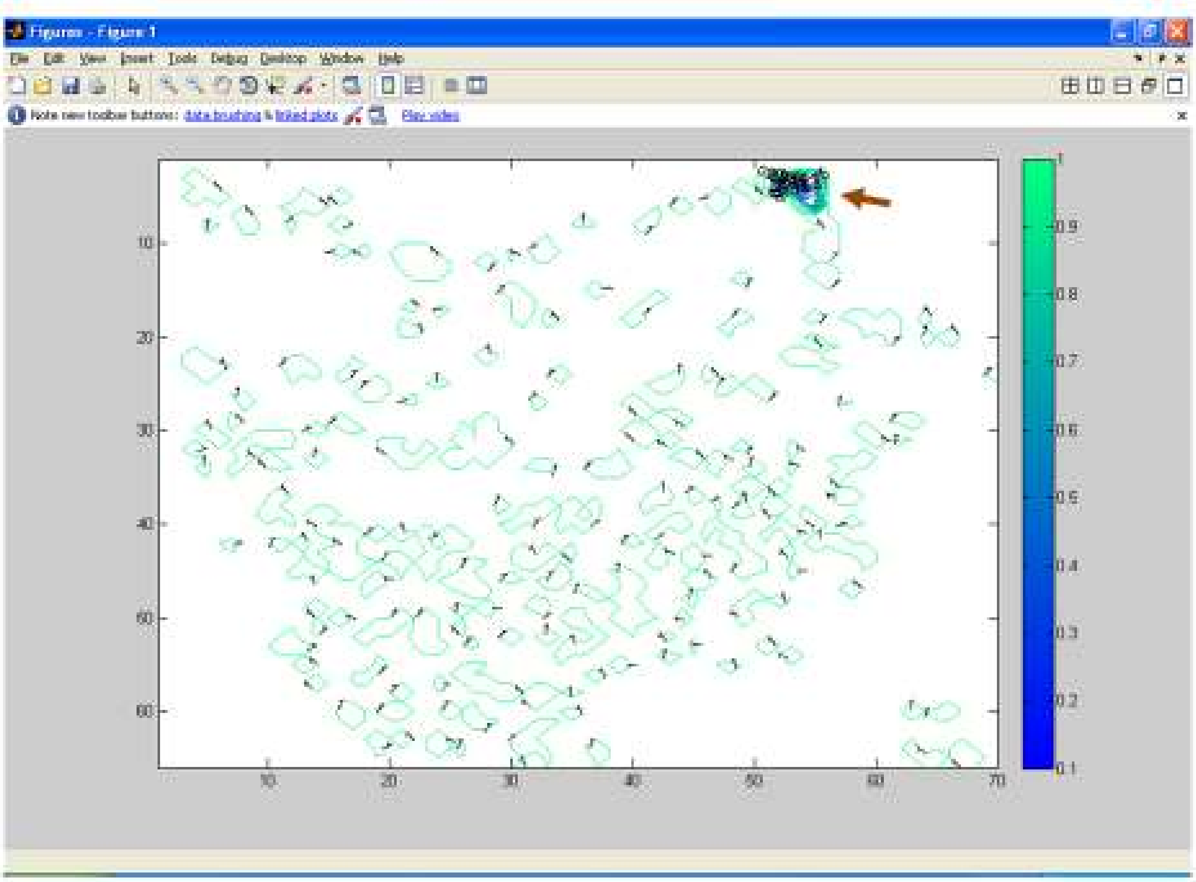

Figure 10. Correlation contour plot between the two maps.

Illustrating Examples

The two compared maps in Figure 11 show the border of the Gaza Strip which is extracted from two maps of different ages. The left one refers to the year 1988 while the other one is published in 2006. "Map Correlation" interface is used to detect the spatial changes involved. The matching result indicates a value of 0.90 correlation coefficient between the two maps (i.e. 90% similarity). Figure 12 illustrates the correlation contour plot which marks the regions of distortion. Generally, this correlation reveals a good matching but the two maps are considered as modern maps (no significant variation in the date of publishing).

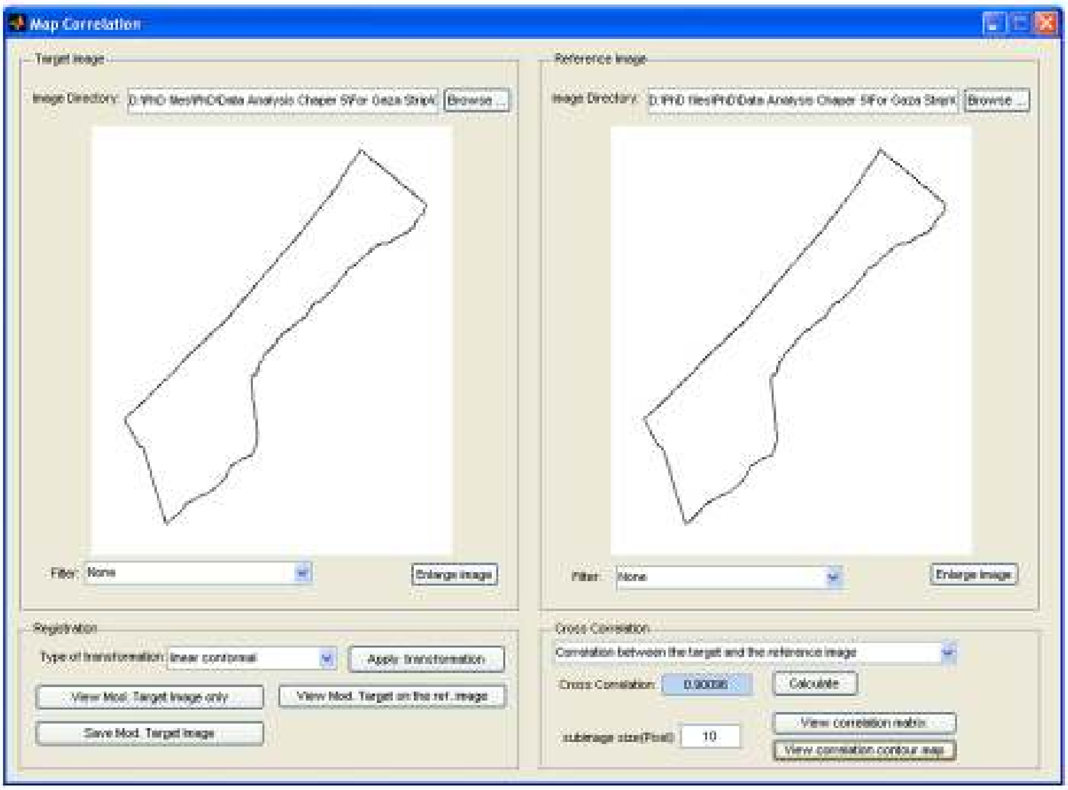

Figure 11. Correlation between two maps of the Gaza Strip.

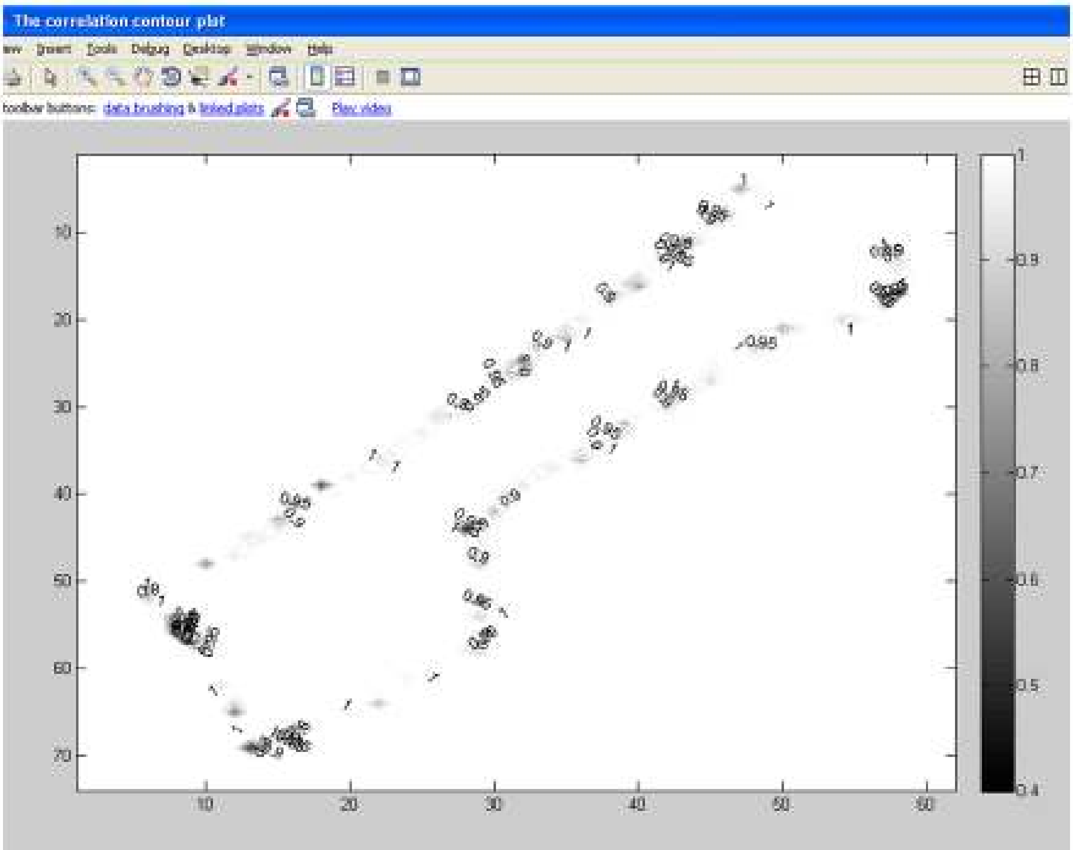

Figure 12. Correlation contour plot between the two maps of the Gaza Strip.

When noticing each map elements, the two maps have different reference datum and projection. The first map was in the Palestine Grid (Datum: Palestine1923, Projection: Cassini) while the second one was based on WGS84 datum and UTM projection. To accurately compare the spatial locations of the features they include, they should be in the same reference coordinate system. Thus, the second map is projected to match the coordinate system of the first one (Palestine Grid). Correlating the maps again shows a correlation coefficient of 1.0 which shows full matching.
Another example is to determine the matching rate between the two maps of Palestine shown in Figure 6. These two maps are illustrated again in Figure 13. The one to the left is a Russian map showing Palestine in the year 1900 and the one to the right shows Palestine in the time of Saul about 1020 B.C.. The two maps have different scales as well as different sizes. The "Map Correlation" Graphical Interface is used to compare these two maps, after converting both in digital form. In the preliminary stage, both map images are first resized to 874 × 552 pixels using a "bicubic" resampling algorithm. There are other algorithms that can be used for this purpose but the "bicubic" usually gives the best results although it takes most time.

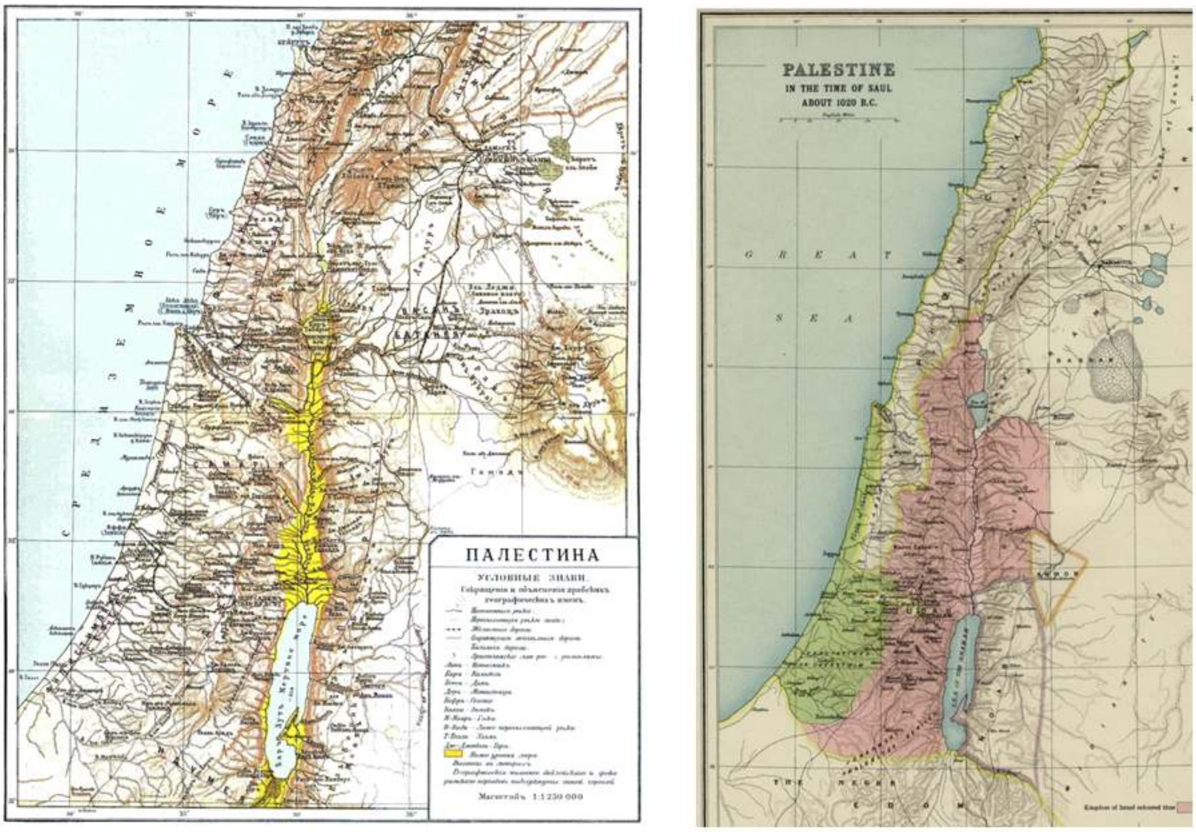

Figure 13. The two compared maps.

A filtering process then is applied to extract some common features from the maps like the borders and the coordinate grid based on the capability of performing some algorithm filters such as the "Nearest Neighbor". These features are shown in Figure 14.

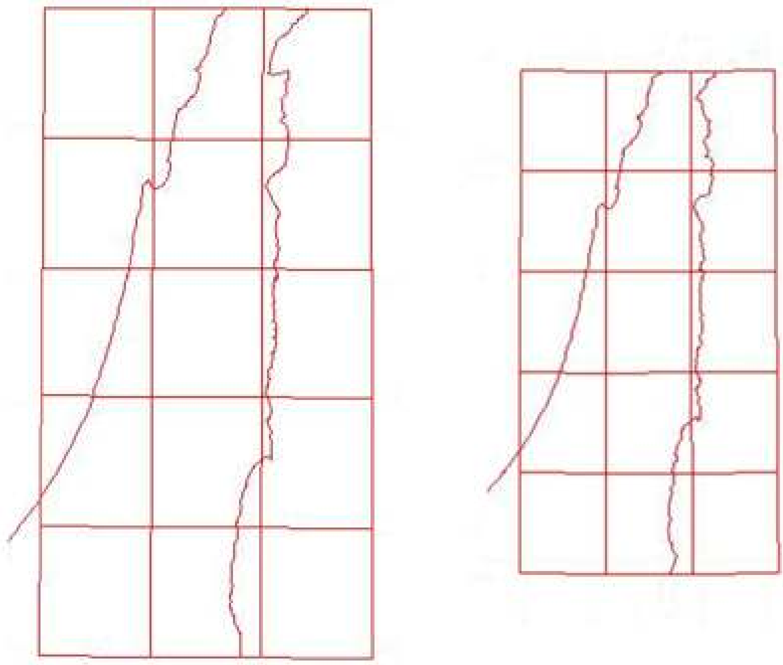

Figure 14. The extracted features from the compared maps.

In the transformation stage, both maps are put in the same coordinate space using the "affine transformation" algorithm. Similarity or any other transformation type can also be used. The overlay of the two maps as transformed by "Map Correlation" Interface is shown in Figure 15.
In the correlation stage, the two maps after transformation are correlated using "Map Correlation" Interface. The result of global correlation shows nearly 0.72 (72%) similarity. This value of correlation reveals good matching according to Balletti and Guerra (2009). Figure 16 shows the correlation process using the developed Interface while Figure 17 illustrates places of distortion using 5 pixels moving window size.

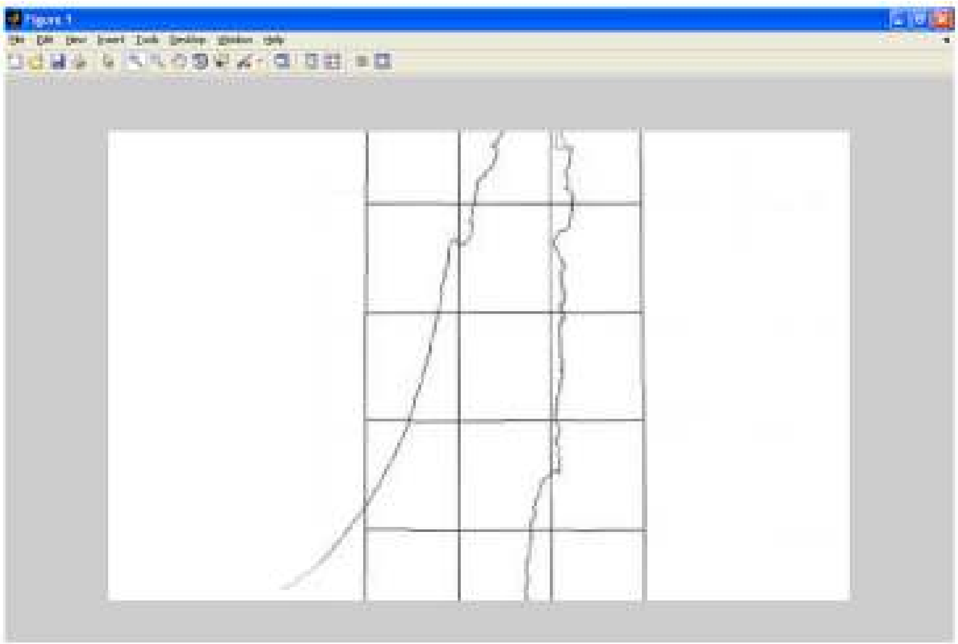

Figure 15. The overlay of the compared maps.

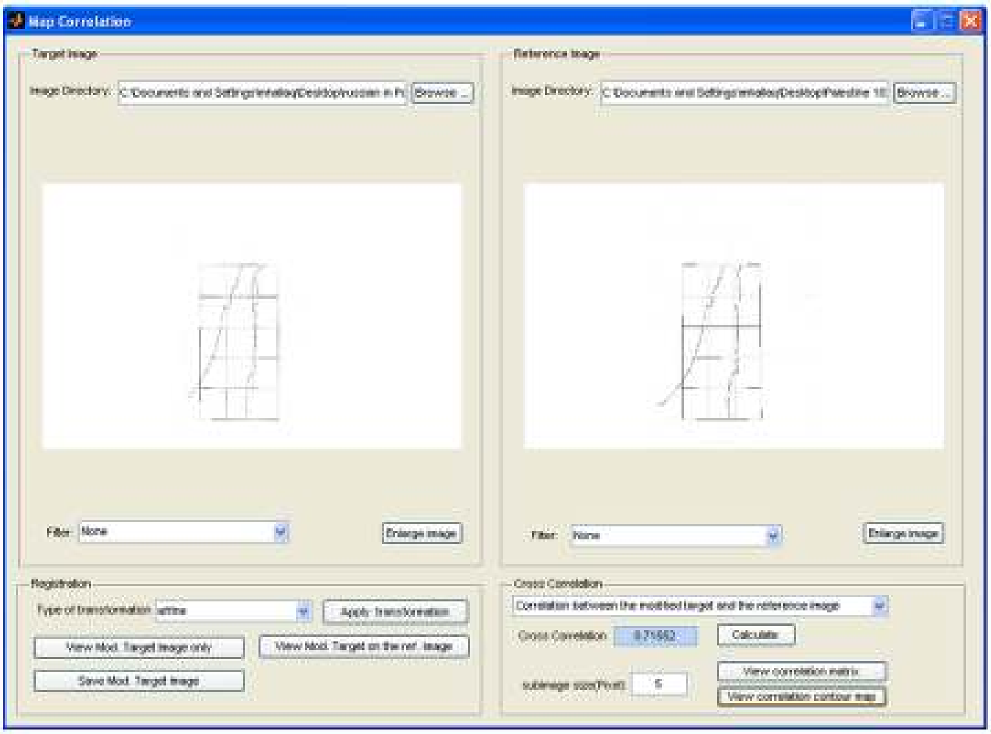

Figure 16. Correlation process using "Map Correlation" Interface.

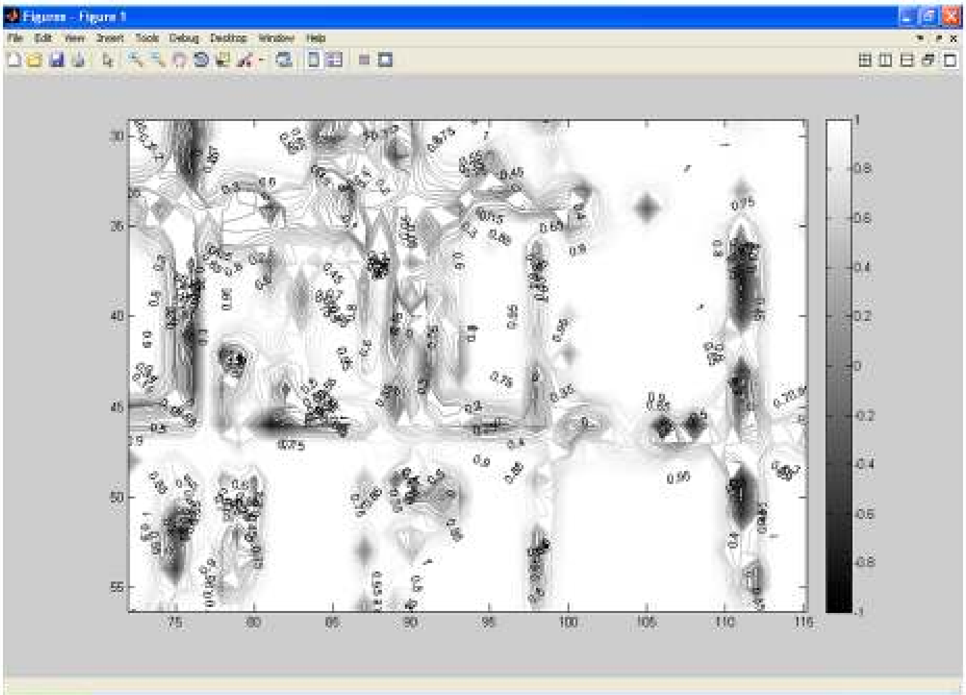

Figure 17. Correlation process using "Map Correlation" Interface.

Conclusion

An analytical methodology has been developed to compare maps and detect the changes which may be involved using map image matching techniques and based on a statistical correlation method. The developed methodology includes four main stages: The preliminary, transformation, correlation and evaluation stages. A friendly Graphical User Interface (GUI), named "Map Correlation", is introduced to facilitate comparing maps. It is very easy to use and contains simple icons to help execute tasks quickly. It is capable of importing, filtering, transforming, overlaying, exporting and correlating maps. Correlation can be expressed in a scalar coefficient or in a correlation matrix format in addition to a correlation contour plot for showing places of spatial changes. A map image matching similarity measure is adopted based on Normalized Cross Correlation and its algorithm is programmed using MATLAB Software. A number of maps are analyzed using the developed Interface, "Map Correlation", to examine its reliability and its working performance and it shows good results.

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