Automatic graves’ orientation detection
A tool for Spatial Archeology

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Abstract—The assessment of the preferred orientation of graves in a necropolis represents an interesting contribution to the study of a civilization. In this paper two different methods are presented. The first one implies a parameterization of the map, i.e. its manual translation into a shapefile, where each grave of the necropolis is separately analyzed and a subsequent automatic orientation of the whole necropolis is achieved. This method proved to be highly reliable in the determining the tomb orientation and entrance direction, although it was quite time consuming, since a fairly important amount of manual work was required. On the other hand, the alternative proposed method using the Radon transform proved to be able to assess the main direction of the whole necropolis analyzing the scanned map image, in a fast and reliable way, without the need of any manual intervention. However in the simplest implementation and for the entire image at once, with the Radon transform it is not possible to determine the versus of the located lines. This is instead achievable when analyzing the single graves. In both cases, the main orientation was correctly detected.

Keywords—radon transform; orientation; spatial archeology

I. INTRODUCTION

The study of spatiality has always been one of the most important issues in Archaeology. Since the beginning, understanding spatial relations has been a crucial factor to identify i.e. past social dynamics. The importance of spatial analyses led even to the advent of specific tracks within Archaeology, such as Landscape Archaeology, Spatial Statistics, Cognitive Archaeology, etc. Thanks to the recent large improvements in documenting methods and analysis tools, such as Global Navigation Satellite System, remote sensing, archaeological geophysics, total stations and digital photography, as well as GIS, time and costs involved in survey activities are much reduced, permitting the rapid and accurate examination of wide areas, making the process of learning more about the historic environment increasingly efficient [1].

Once data have been acquired, they need to be processed to be analyzed, categorized, and ultimately understood.

The Etruscan Necropolis of Tarquinia (Italy), counts a large number of tombs, estimated in nearly 6,000 graves, some of which have been located but have not been excavated yet. The necropolis, also known as Monterozzi, is famous for its 200 painted scenes, the earliest of which date from the 7th century BC (http://whc.unesco.org/en/list/1158). The depiction of daily life in the frescoed tombs, many of which are replicas of Etruscan houses, is a unique testimony to this vanished culture. Moreover many of the tombs represent types of buildings that no longer exist in any other form. The cemeteries, possibly replicas of Etruscan town planning schemes, are some of the earliest existing in the region. The known tombs of the Monterozzi Necropolis have been included in a map by Fondazione Lerici (Politecnico di Milano) on behalf of Soprintendenza per l’Etruria Meridionale.

This map is the result of the geophysical prospections carried out by the Lerici Foundation during the years 1956-1961 and 1966-1977. Different survey methods (electrical, seismic and magnetic) were compared, in order to investigate and represent the structure of the necropolis, and precisely the “Calvario” cemetery area. At first, the survey was made exclusively by the potentiometric method based upon the measurement of the soil resistivity, employing electrical resistance equipment, crustily designed by the Lerici Foundation: potentiometer with electronic volt meter, photographic and electric boring drills, and a periscope. Several hundreds of unpainted tombs were pin-pointed by electrical anomalies caused by the cavities of the entrance passages of the tombs. Then seismic and magnetic methods were applied. The seismic one was usefulness, unlike the experimental use of a proton-magnetometer, more efficient than the electrical survey. Magnetic readings were then taken, which were made at one-meter intervals, and a magnetic contour map was defined mapping these recordings on a grid pattern. An extensive drilling program and test excavations assisted the interpretation of the geophysical anomalies found during these archaeological campaigns.

About 1300 tombs were located and they are represented with a simple contour and a progressive identification number, indicating the discovery order [2-5].
The form of an Etruscan tomb is varying depending on the cemetery, however in Tarquinia they are mostly chambers tombs, all cut in the rock (a compact layer of marine limestone, called “Macco”) and accessible through sloping or stepped corridors, trench-like, called “dromos”. Most of the tombs were made for a single couple and consist of one or multiple burial chambers, at depth varying from 2 to 6 meters below the surface.

On the map the tombs appear as essentially defined by a squared chamber and a long corridor (see fig. 3 and 4). The long access strip defines the orientation of the grave.

II. PROBLEM STATEMENT

It was the aim of this research to estimate the general orientation of the necropolis, i.e. to assess whether there was a general preferred direction. Moreover, the orientation of each single tomb needed to be determined in order to fill a database of information related to the Tarquinia site.

The orientation of the graves can be estimated with a certain degree of approximation, evaluating the position of the entrance corridor (“dromos”), since in practice the walls of it and those of the burial chamber, are not perfectly parallel or orthogonal among each other. Two different challenges have been faced:
A. Single tomb orientation: The orientation of a grave is defined as the direction of the dromos entering the tomb.

B. General necropolis orientation: The general orientation in the necropolis is defined as the most occurring direction of the dromos.

In order to achieve such results, two different approaches were tested:

1. identification of the orientation of a single tomb with a geometric approach (Section IV): the orientation of the tomb is then defined considering its outlines and the burial chamber position, and subsequently the general orientation of the necropolis is computed considering the distribution of all the graves.

2. identification of the global orientation using the Radon transform (Section V) and the detection of lines occurrence in concurrent directions in the entire map. The orientation of a single tomb is the computed separately, by first segmenting a single tomb area in the necropolis’ map.

III. DATA AND TEST FIELD

The input source was an old map (with georeferencing information), as described previously, printed on a paper (fig. 1). It was digitized using a professional scanner, so that the distortion could be reduced to the minimum, however several rings and dirty areas remained visible, together with the original map’s reference grid. While for the second approach (Section V) the map was used as it was, for the first approach (Section IV), a manual editing was necessary in order to erase such noise and most importantly to digitize the intended information. To achieve that, the borders of each tomb were separately defined. The manual digitization of each tomb was performed using the QuantumGIS software. A shapefile of the whole necropolis was achieved (fig. 3 top). Each grave was recorded as a sequence of connected points that traced the graves’ contours. The digitized tombs where also coupled with a database containing, for each one, information like dimensions, period, geolocation, etc. as well as the spatial orientation.

The plot of a single tomb extracted from the digitize map of the Tarquinia’s Necropolis (fig. 4 a) was also employed to test the performance of the Radon transform alongside with a more complex map of a single tomb of the Etruscan Necropolis of Cerveteri (fig. 4b).

IV. GEOMETRIC ALGORITHM

This algorithm was developed in order to define the orientation of each grave separately and to provide the frequency of each different orientation in the whole necropolis. The algorithm exploits the peculiar geometry of the tombs that are usually characterized by long and straight corridors that conduce to one (or more) larger and squared room (i.e. burial chamber).

Exploiting this geometrical features, an automated algorithm for main direction detection of the digitized contours was developed in Matlab. The algorithms exploits the information provided by each segment defining the grave’s boundaries and the a priori knowledge about the particular shape of the Etruscan graves. The developed method works according to the following steps:

- The segments defining each tomb in the digitized map are extracted from the file and linked together in order to reconstruct the borders of a single tomb. The first and the last point of the tomb coincide to define a close polygon.
- The number of segments is usually high: some of them are almost aligned and could be merged together. The direction of each segment of the tomb is compared to the previous and the following ones: if the difference in direction is lower than a defined threshold (usually 5-10°) the segments are merged deleting the point of junction between them. The process is iterated until all the possible groupings are performed.
- The longest segment of the tomb contour is defined (orange line in fig. 5). This line is generally in correspondence of dromos’ walls. Only in very few cases it corresponds to the burial chamber’s walls. The orientation of this line is then computed.
- The orientations of all segments are compared to the longest one and the orientation differences are evaluated. Only the lines with orientation differences lower than a threshold (15°) are considered for the following main orientation computation (blue lines in fig. 5).
- The main orientation (gray dashed line in fig. 5) is computed considering the selected segments and weighting
their contribution according to their length: short segments contributes less than long ones. The grave orientation defines the main axes along which the grave is expanded but, it is not possible to define the entrance direction.

- The gravity center (GC) of the grave is defined: the computation is performed considering the segments’ vertices coordinates and computing their mean value in both directions (purple point in fig. 5).
- The burial chamber position is then defined considering the longest segment that lies in a perpendicular direction respect to the main direction (red line in fig. 5). This segment usually corresponds to the back wall of the burial room.
- The main direction is finally defined considering the versus from the GC to the burial chamber’s wall (green arrow in fig. 5).

This process is repeated for each tomb. A cumulative frequency histogram of the orientation directions is then derived over the whole necropolis.

V. RADON TRANSFORM

In automated analysis of digital images, a sub-problem often arises of detecting simple shapes, such as straight lines, circles or ellipses. In many cases an edge detector can be used as a pre-processing stage to obtain image points or image pixels that are on the desired curve in the image space. Due to imperfections in either the image data or the edge detector, however, there may be missing points or pixels on the desired curves as well as spatial deviations between the ideal line/circle/ellipse and the noisy edge points as they are obtained from the edge detector. For these reasons, it is often non-trivial to group the extracted edge features to an appropriate set of lines, circles or ellipses. The purpose of the Radon [6] transform is to address this problem by making it possible to perform groupings of edge points into object candidates by performing an explicit voting procedure over a set of parameterized image objects.

Applying the Radon transform on an image \( f(x,y) \) for a given set of angles can be thought of as computing the projection of the image along the given angles. The resulting projection is the sum of the intensities of the pixels in each of such direction, i.e. a line integral. In particular, if we consider a straight line which can be defined by two parameters, denoted by \( \rho \) and \( \theta \) in polar coordinates (where \( \rho \) represents the distance between the line and the origin, and \( \theta \) is the angle of the vector from the origin to this closest point), the result of the Radon transform of an image depicting such line is a new image \( R(\rho,\theta) \) where the highest intensities are corresponding to the \( \rho \) and \( \theta \) of the line in the image.

In our case, for the assessment of the general orientation of the necropolis we decided to identify, and group, the majority of the longest lines in the image associating the direction of the walls of the dromos, with the direction of the grave. Moreover we selected also, as strengthening assessment, the presence of a numerous second group of lines oriented at 90 degrees with respect to the previous group. For the analysis of the single tombs we aimed at evaluating the performance of this algorithm on different types of graves, defined as a simple polygon or more complex ones. The Radon transform was applied using the Matlab implementation, choosing to evaluate the results for \( \theta \in [0, 180] \), since the direction of a line shows a periodicity of \( \pi \). As main limitation, the main entrance versus for the whole necropolis, cannot not be defined using this method, on the other hand the direction assessment can be achieve in a very short time. For a single tomb the versus can be identified, as described in sec. VI.B.

VI. RESULTS

Both methods were applied in order to estimate the prevalent direction of the dromos’ graves. The results achieved by different methods have been compared in order to evaluate their reliability and the completeness of the extracted information.

A. GEOMETRIC ALGORITHM

The described algorithm was applied on each grave of the dataset. The performances achieved by the algorithm were assessed by visual inspection. In fig. 6 the results on several dromos are shown: the blue lines represents the conjunction between the gravity centers and the middle point of the burial chamber’s wall. The main orientations has generally provided good results. Some wrong entrance directions can be detected in graves characterized by irregular shapes or with dromos of reduced dimensions. However, the algorithm has shown to provide correct solutions in most cases and since it only seldom fails, mistakes do not significantly influence the orientation results.

![Fig. 6. Several dromos in the necropolis with the estimated directions and middle points.](image)

The orientation were grouped in 72 different classes (5° amplitude for each class). The number of classes was the right balance between orientation uncertainty and sensitivity of the method.

They were visualized on a wind rose in order to visually associate the relative frequency of each orientation to the
considered direction (fig. 7). As it can be easily understood, the north-east direction (between 40° and 60°) is largely predominant with respect to the others. A secondary direction can be detected in the east, south-east direction. These results are in agreement with, and therefore validate, the results achieved by the Radon transform described in the following section.

**Fig. 7.** Wind rose visualization of the dromos main orientations in the necropolis, as achieved with the geometric method.

**B. RADON TRANSFORM**

Firstly the Radon routine was applied to the image of the single tombs (fig. 4a and 4b), both as simplified and more complex relief.

As visible in fig. 8, in both cases the outcomes show with rather high accuracy the presence of the longer segments indicating the dromos borders. Therefore, estimating the direction of every single grave is possible by applying the routine to the related image. In this case it is also possible to identify the entrance versus, since it is possible, analysing the $\rho$ parameter to locate the relative position of the dromos, with its longest lines, and the back wall of the burial chamber, with the second longest line.

The Radon transform routine was also applied to the unprocessed image of the entire map (fig. 1). The corresponding transform image is shown in fig. 10. As we can observe in the image, despite the considerable amount of noise in the input image, including the lines of the cartography, a good estimate of the main directions is achieved. As shown in fig. 9 and fig. 10, the same distribution of lines is detected as in the digitized map (fig. 3 - bottom) as input. Peaks are to be found in the $\theta \in [45, 60]$ range, which is in close agreement with the results achieve with the geometric method.

**Fig. 8.** Radon transform on a shaped single tomb (top) and the corresponding scanned noisy tomb. The 3D representations on the right show they both have main peaks at the same frequencies.

**VII. DISCUSSION AND CONCLUSIONS**

The assessment of the preferred direction in a necropolis represents an interesting contribution to the study of a civilization. In this paper, to this aim, two different methods have been developed and presented using a map of the tombs in the Etruscan Necropolis of Tarquinia (Italy). The first one implies a first vectorization of the map, i.e., its manual translation into a shapefile using the QuantumGIS software, where each grave of the necropolis was separately entered in the database. A subsequent automatic orientation of each map was achieved by considering the geometrical peculiarities of the Etruscan tombs of this necropolis, such as the presence of long, straight dromos defining the entrance versus. Using this method, the orientation of each tomb could be defined and the global orientation of the necropolis was attained by computing the most frequent occurrences. This method proved to be highly reliable in the determining the tomb orientation and entrance direction, although it was quite time consuming, since a fairly important amount of manual work was required. On the other hand, the method using the Radon transform proved to be able to provide the main direction of the whole necropolis simply analysing the scanned map image, in a fast and reliable way, without the need of any manual intervention. However, in the used implementation applied to the entire image, the Radon transform cannot determine the versus of the located lines. This is instead possible when analysing the single graves, since the longest lines with an about orthogonal direction compared to the dromos line, most likely represents the back wall of the burial chamber. The relative position of dromos and burial chamber can thus give an indication about the entrance versus. In both cases, a principal orientation in north east direction and a secondary orientation in south east direction have been detected.
Some improvements will be implemented in the geometric algorithm in order to further reduce the number of wrong tomb orientations. In particular, a more general approach will be adopted to determine the main orientation in order to correctly analyse tombs with short dromos too. Then, further improvements will be implemented in the gravity center determination, as this point is wrongly located when multi-chamber tombs are considered.

As far as the Radon approach is concerned, a more advanced version will be implemented, which will be able to automatically assess the versus alongside the entrance direction. Such information can be inferred by automatically segmenting the entire map in tombs and exploiting for each of them, the Radon transform properties. Moreover the idea of using Radon transform for assessing the main direction of the tombs in a cemetery map could also be extended if available, to 3D data, by analytically evaluating the three main directions of the cemetery 3D model.

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