ANALYTICAL AND QUANTITATIVE METHODS FOR THE ANALYSIS OF THE GEOMETRICAL CONTENT OF HISTORICAL CARTOGRAPHY

Caterina Balletti
DIIAR Dipartimento di Ingegneria Idraulica, Ambientale e del Rilevamento
Sezione Rilevamento - Politecnico di Milano
P.zza Leonardo da Vinci 32 – 20133 Milano
balletti@brezza.iuav.it

Working Group V/5

KEY WORDS: : historical cartography - plane transformations - geometrical analysis - geo-referecing

ABSTRACT

The preliminary remark to the research described in the paper is the utilization of GIS for the management and the analysis of geographical-territorial data in their historic-temporal evolution, or rather to arrange historical information according to a key of spatial reading.
In the development of a territory the historical cartography has had a deciding role.
This means the necessity of getting data and informations from maps not only temporally arranged but even spatially referenced.
The historical maps, however, for their metrical and semantic characteristics, are rather difficult to reference with the commonly used procedure. Often times in fact, they contain topographical and not metrical information and their insertion into a GIS is actually impossible.
The aim of the research is to recover the metrical content in historical maps (particularly portolan charts, *Isolari*, perspective views of towns of XV-XVI century) using analyses which lead to a definition of a methodology for the quantitative analysis of historical cartography.
This implies to use procedures that treat of:

- global transformations: such as projective, affine, Helmert, polynomial transformation;
- local transformation: such as finite element transformation, point based or feature based warping.

Historic cartography has been, for long time, a subject of study by the historians and therefore, it has been considered as an archive document, a testimony of a certain period in the history of a territory, of a city. The study initiated and proposed in this paper faces, rather, the historic cartography according to an approach which is typical of the current cartography: extract territorial information which has been spatially referenced.
The historic cartography, within the problems of using the GIS, is surely a field in which the questions relating to the referencing assume great interest.
But how is it possible to geo-reference ancient charts? Often times they present some common characteristics such as:

- an uncertain metrical content
- a non definite system of reference
- representational scale
- unknown unit of measure
- an approximate projected system,
- non definite surface of reference
- not recognizable projective system:
- semantic content difficult to interpret.

Such characteristics in the maps and charts from varying eras are found in greater or lesser measures, and consequently, it is necessary to make specific considerations when faced with each and every individual map.
A map has different levels of accuracy, planimetrical, topographical, proportional, conventional, hierarchical, which are to be distinguished and to which the reader has to adapt according to the function that the map assumes: in a sea chart, distances, lands and bearings are characterized by a high accuracy. Harbors and mouths are positioned correctly and, often, magnified as regard the graphical scale of the chart. Instead, coasts are represented in a conventional way, such as the topography of the hinterland (such as mountains or representative architectures of a place).

So there are two different categories:

- maps and plans of cartographic interest: executed for technical and public purposes, they represent geographical outlines, respecting proportional relations between parts. In this case, the geographical configuration is in orthogonal projection, while topographical characteristics are seen in perspective or in a front view, according to a schematic conventional look. Wordings offer practical knowledge.

- maps and plans executed for didactic purposes: their aim were not to give geographical informations, but to illustrate.

The fact remains that, in general, the assigning of a correct metric support is very important for the use in cartography, not only as a document for the archives, that is, of a qualitative nature, but a true cartography from which to extract quantitative information.
An idea that must guide and propel in this direction is that it is important to keep in mind that these charts have been created as charts, that is, with an operative and practical purpose, and that they were used as such. Perhaps the concept of metrics has changed, or more simply, the acceptable accuracy threshold has changed over the years.
They are, however, representations of the territory and therefore are informational.
How can a piece of information that is arranged on the territory but non metrical be transferred onto a metrical support (GIS)?
The preliminary remark is to recover the metrical content in historical maps using analyses which lead to a definition of a methodology for the quantitative analysis of historical cartography.
This means to use procedures of referring that treat of:

- geometrical transformation based on global parameters which are calculated using a high number of control points;
- geometrical transformation based on local parameters.

The main characteristics of plane global transformation can be summarized in the next few steps:

- the source image is transformed on the base of parameters calculated before the transformation (resampling);
- parameters are valid for each point of the image;
- a larger than needed number of points is used to estimate to the least squares the parameters;
- an estimate of the results of transformation is given by usual statistic parameters.

These transformations are used in the referenced procedure as a global transformation. In the same time they are used to evaluate the presence and the distribution of deformation in the residual analyses.
In practice, it has to do with the traditional plane transformations that allow for the passage from system (o,x,y) to system (O,X,Y); the general equation which regulates such a passage is represented by a polynomial of the nth order like so:

$$X = \sum_{i=0}^{m} \sum_{j=0}^{n} a_{ij} x^i y^j$$

$$Y = \sum_{i=0}^{m} \sum_{j=0}^{n} b_{ij} x^i y^j$$

The procedure which utilizes this polynomial is known by the name of *rubber-sheeting*. In the case in which only linear terms are taken into consideration, we are brought back to the linear transformations commonly used in the survey discipline (affine, conformal, projective).

The equations are exactly satisfied if the number of points known n = ½ p, and the number of the parameters are taken into consideration. It would seem evident therefore that if there are a great number of known points to use and if an exact solution is needed then elevated grade polynomials must be used. In this last case, non linear transformation (≥second order) are applied.

In general a larger than needed number of points is used and the value of the parameters is estimated to the least squares; in this way it is possible to evaluate the results of the transformation.

The local transformations are those in which the parameters of transformation are calculated for each single point of the image and have a local validity. The scope is to distort only a part of the image while leaving the rest of the image unaltered.
To this second kind belong finite elements transformations and that ones based on points or features (usually known as *point based warping* and *feature based warping*).

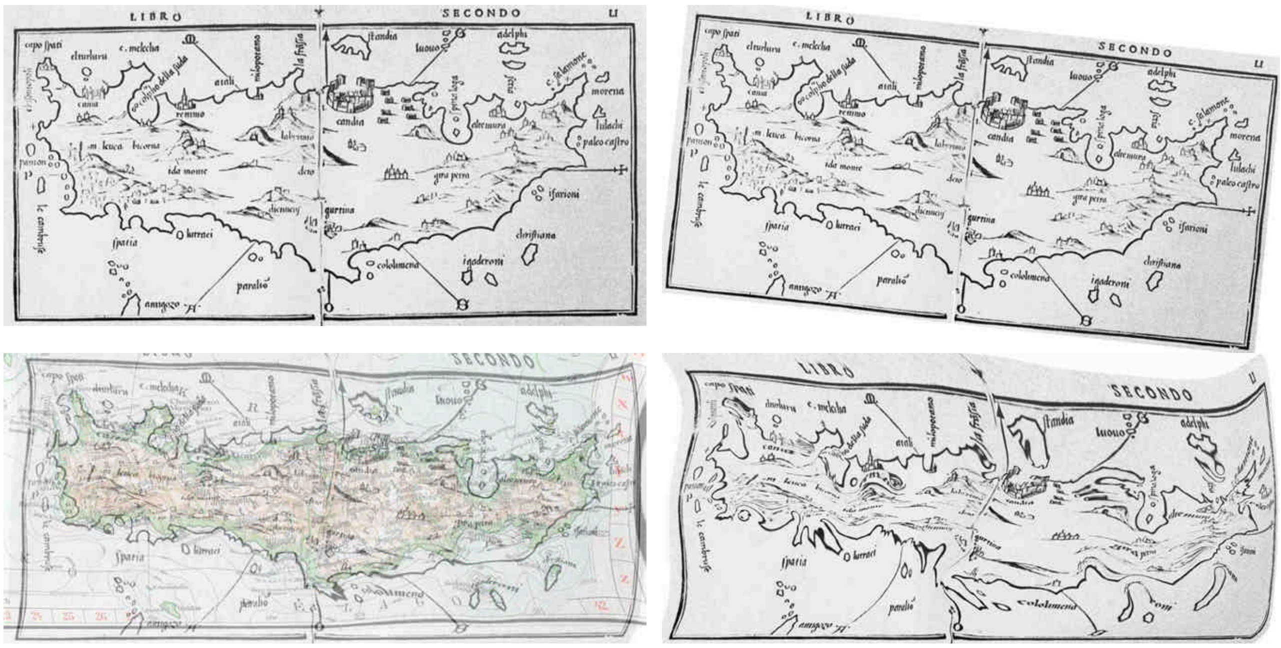


figure1. Creta in the Isolario of Benedetto Bordone (1628). The map has been georeferenced to an actual map using a helmert transformation and then a local point based transformation

This type of algorithms has the advantage of allowing for an optimal adaptation of the image to modify with respect to the points of reference. The usable parameters allow for an exact transformation for the points known and an approximate transformation for all the others. All of the points are utilized and so it is impossible to verify the result of the operations.
In simple words, a local transformation offers the possibility to transfer the reference map geometry to that one that has to be transformed.
In a finite elements transformation the image to be geometrically correct is divided in a triangular mesh starting from the control points (the algorithm is that one of the Delaunay triangulation, adopted because of the smaller angle variations of the resulting triangles). For each triangle, which vertices correspond to three control points, an affine transformation is applied.

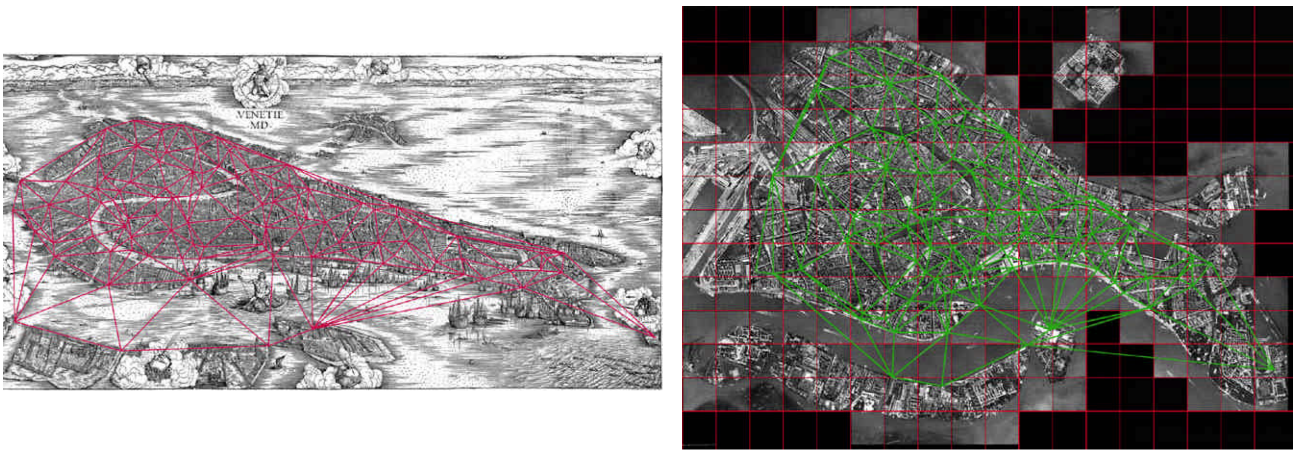


figure2. Delunay triangulation in finite element transformation

For the analytical and quantitative methods described above, some privileged experimental typology of maps have been identified:

- perspective maps;
- portolans or sea charts;
- *isolari* .

1.1 Applications

1.1.1 Perspective views

The study presented has concentrated primarily one the perspective views, which, if on the on hand, these have the advantage of being easily understandable in so far as the perspective is among the methods of representation which is most widespread, on the other hand, it is in fact, not measurable, if not by resorting to tricks which implicate a deep understanding of the descriptive geometry. The choice to use the perspective views of Venice by Jacopo de' Barbari was motivated not only by celebratory, but especially for the geometric and cartographic characteristics of this map that represents the most exciting example of the new method of representation of the city based on perspectives. For the actual reference cartography for referencing, the photoplane of Venice was chosen. The idea that the perspective construction of the view might have been realised beginning with a plan and using elevations is fascinating for those involved in cartography because it presupposes the existence of a survey of the city or at least, given the particular character of the urban structure of Venice, of a series of reference points probably positioned in bell towers and surveyed using triangulation or a polar coordinates.

figure3. The perspective view of Venice of Jacopo de' Barbari

The studies have been addressed to evaluating the shifting of the view with respect to a "correct" geometry.
In the study of the view, the planimetric part was separated from the altimetric part, so that the information regarding the elevations were studied and evaluated separately. Even considering the view as a perspective construction based on geometric data surveyed directly or extracted from previous charts, the data on the elevations would result in not being easily worked with together with the planimetric data.
the view of de' Barbari, relative to plane of the attachment of the buildings to the ground, of the canal side walkways and of the canals themselves, can be considered as the transformation of a planimetry of the city. Or rather, it is possible to obtain a view which corresponds geometrically to the city in the 1500's, taking an orthogonal projection of the city and modifying it according to a plane transformation.
Among the various applicable and presented transformations (conform, polynomial, affine) the projective transformation with eight parameters has been chosen. This transformation is equal to the central projection of one plane on another, that is, in our case, to the placing in prospective of a planimetry. From this application, it was possible to evaluate the shifting of the view of Jacopo de' Barbari from a rigorous central projection.
Superimposing a regular grid to the photoplane of Venice and mapping it onto the view through a transformation to finite elements, a representation of the current city of Venice is obtained with the geometric characteristics of the 1500's produced work. From the comparison with the correct prospective of the same photoplane (previously obtained from the projective transformation) the modifications by the author can then be seen.
In an analogous way, it was possible to reconstruct the planimetric image of Venice from the 1500's, or rather, by mapping the view onto the photoplane.
From the combined application of the transformation to finite elements and of the projective transformation, the elaborations have been realised which have led to modify the view, returning it, for the planimetric part, to a correct central projection.

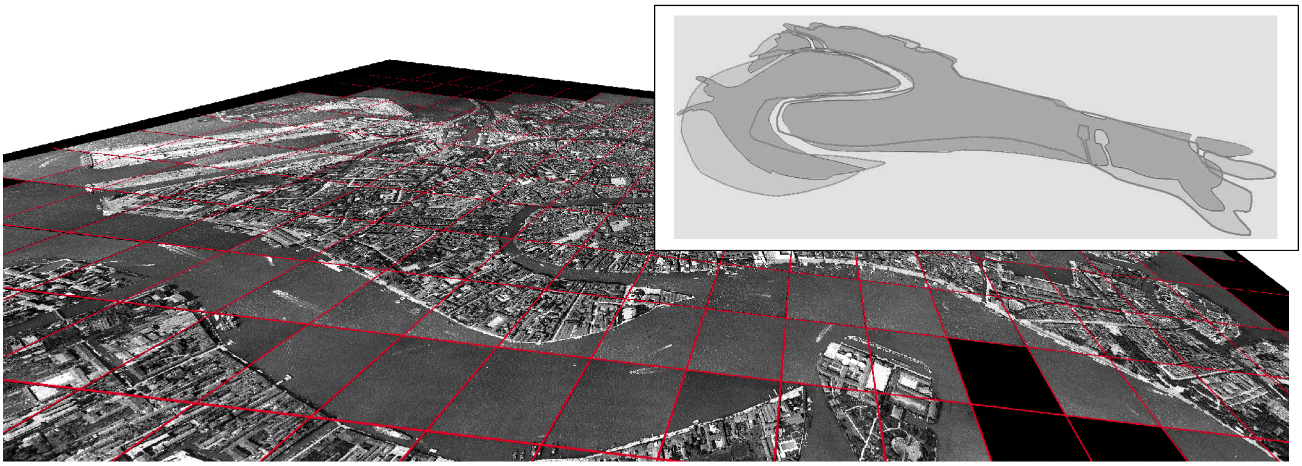


figure4. A perspective view of the actual plan of Venice obtained applying a projective transformation. In the upper corner the superimposition of the scheme of the original view and of the correct one to underline the deformations introduced by the author.

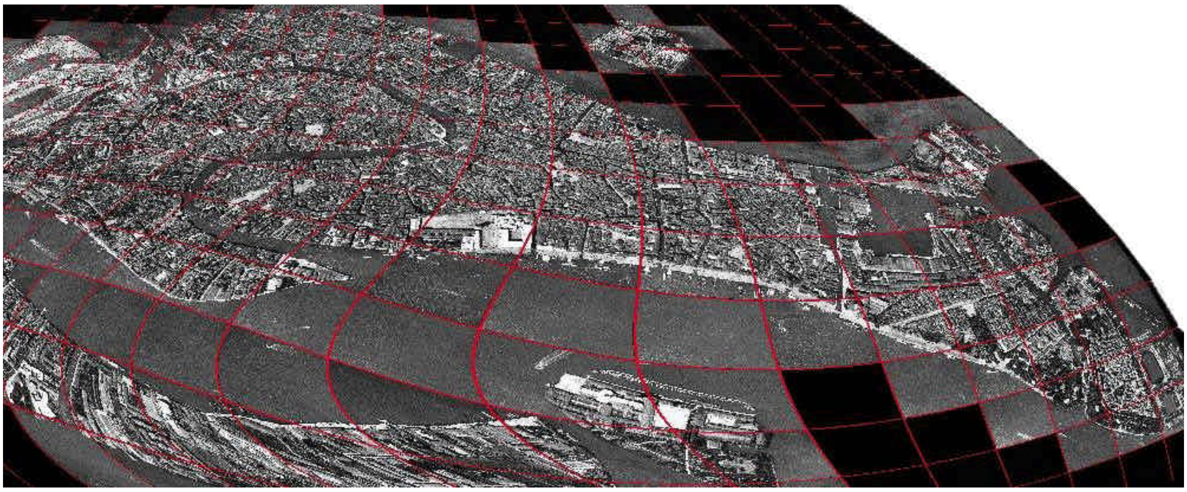


figure5. Polynomial transformation: 20 parameters

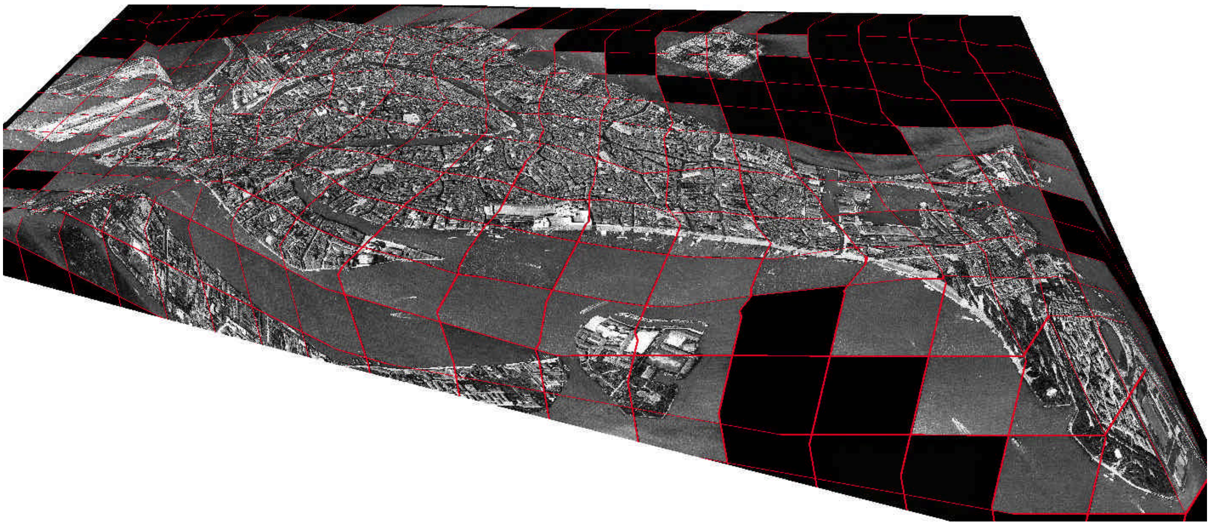


figure6. Finite elements transformation: applying this transformation, the new image of the photoplane obtained has the same geometry of the de' Barbari one. The irregular deformation of the grid underlines that the view is not a correct perspective.

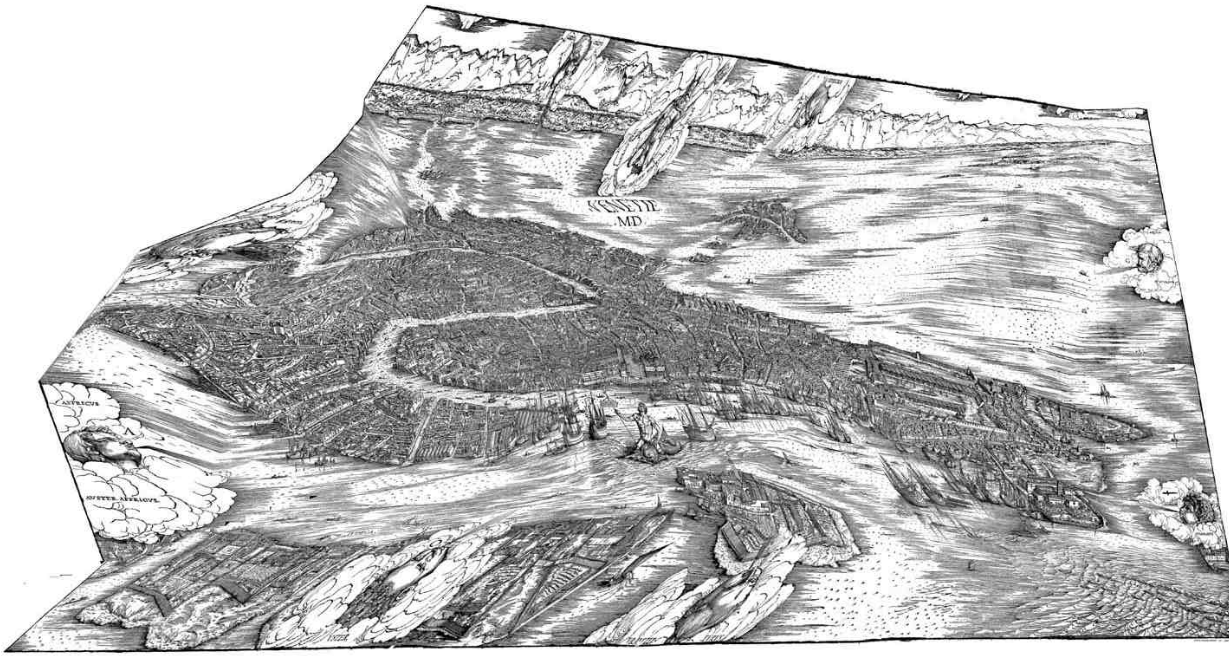


figure7. de' Barbari's view transformed in a correct central projection.

1.1.2 Portolans

The second application, still in progress, is on the ancient sea charts, which drawing was not built on mathematical principles, but on the position of represented points, surveyed by reciprocal bearings and distances.

In these maps were absolute the concept of bearing based on wind roses.

Even if portolans were thought as maps without a projection, the lack of clear and visible coordinates doesn't mean lack of a projective system. If some medieval charts don't obey any coherent geometrical (or cartographic) reticulate, portolans can be classified as "orthogonal" maps.

In a new research (C. Boutoura, Scoperta di un il reticolato geografico in una carta nautica dell'Egeo del XVI secolo, catalogue of the exhibition *Raggi di Vento sul Mare*, Tessaloniki, January 2000) the connection between the wind roses system and the geographic reticulate in sea charts is came out.

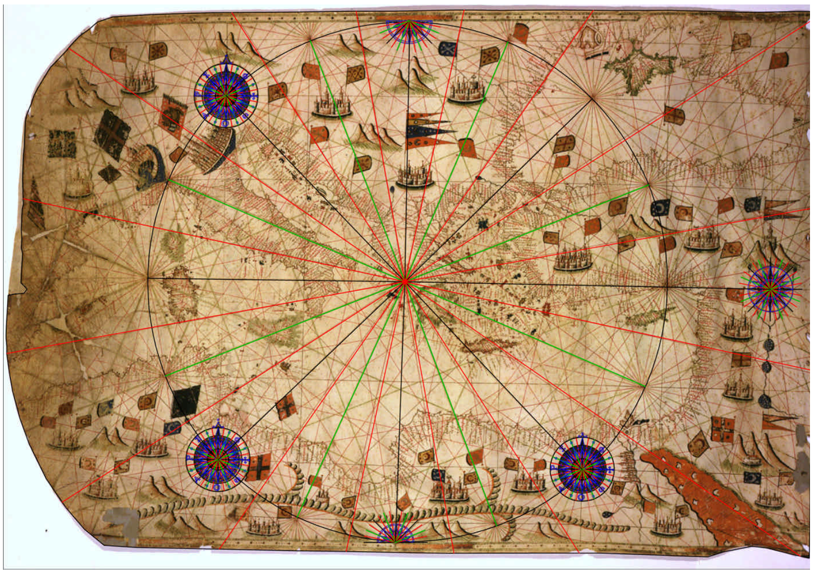
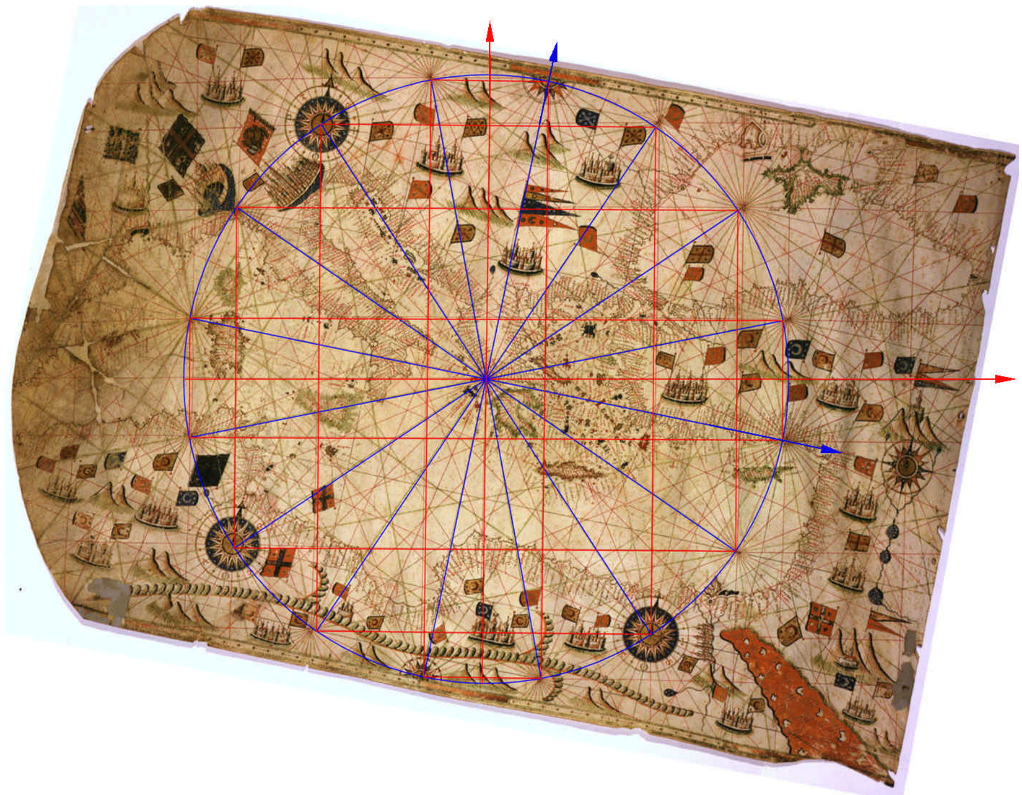


figure8. Sea chart of Sideri of the XVI century. The elaboration underlines the wind roses system

The experimentation carried out looks at a series of sea charts, dated in the period before and after the publication of the famous Mercator projection, compared and geo-referred respect to a today sea chart in Mercator projection.

The analytical study of maps deformations provides a methodology based on, in a first step, a global transformation that allows a correct bearing of the old map and, in a second time, the application of local transformations (finite elements) for a better comparison - correspondence with the reference cartography.



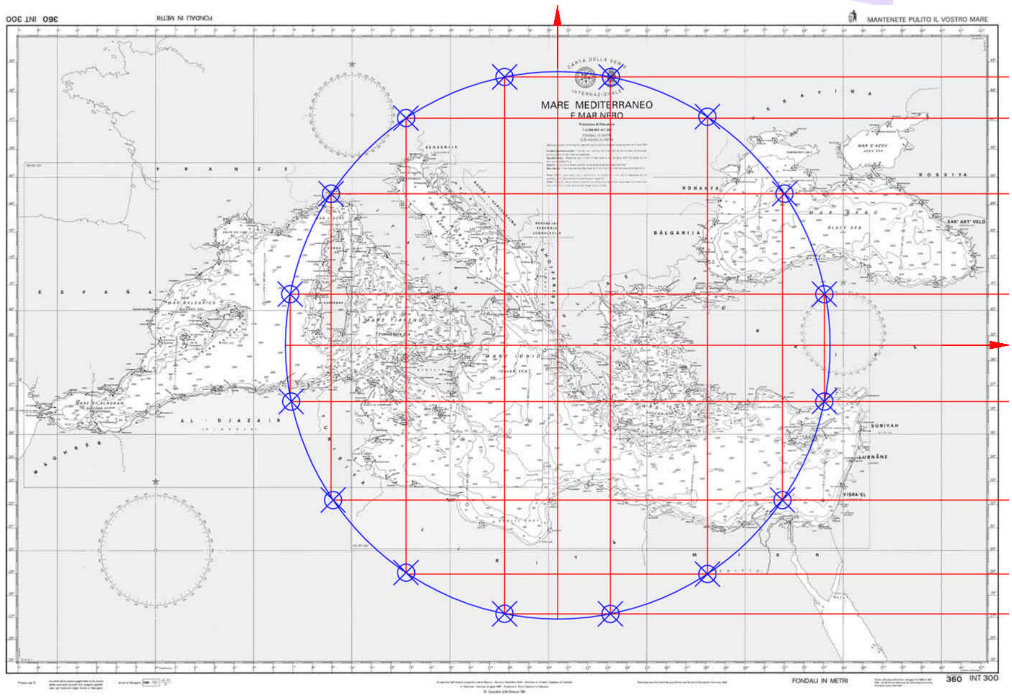


figure9-10. The sea chart of Sideri after a global plane transformation and a today sea chart in Mercator projection.. The scheme shows the relationship between the wind roses system and a geographical reticulate.

REFERENCES

C. Balletti, F. Guerra, C.Monti, E.Livieratos, C.Boutoura, *Studi ed elaborazioni informatiche e infografiche sulla veduta prospettica di de'Barbari,* in catalogo della Mostra "Jacopo de'Barbari.Carte e panorami di città nel '500", Museo Correr, Arsenale editrice,Venezia, novembre 1999.

C. Balletti, F. Guerra, C.Monti, *Analitical methods and new tecnologies for geometrical analysis and georeferenced visualisation of historical maps,* in The International Archives of Photogrammetry and Remote Sensing, Vol.XXXII, Part 6W8/1, ISPRS WG VI/3 e WG IV/3 , Bridging the gap, Atti del meeting tenutosi a Lubiana, il 2-5 febbraio 2000.

C. Boutoura, *Scoperta di un il reticolato geografico in una carta nautica dell'Egeo del XVI secolo*, in Catalogo della mostra sulla cartografia nautica del '500 "Raggi di vento sul mare", Centro Nazionale Ellenico per le Carte e il Patrimonio Cartografico, Salonicco 24 gennaio – 13 febbraio 2000.

C. Balletti, F. Guerra, D. Miniutti, *GeoPlanTransf: a software for the georeferencing of digital images by using plane trasformations,* in International Archives of Photogrammetry and Remote Sensing, ISPRS WG VI/3, Parma,15-19 febbraio 1999.

Balletti C., *An informative system for the management of historical maps,* in Atti del 5th Hellenic Cartographic Conference "Large Scale Cartography: City Maps", XEEE, Salonicco, 25-27 Novembre 1998.

Fuse T., Shimizu E. Morichi S., *A study on geometric correction of historical maps*, in International Archives of Photogrammetry and Remote Sensing vol XXXII, Part 5, Hakodate 1998;