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3D Digitization and Web Publishing of an ISMAR Cartographic Heritage: Historical Maps of Venice Lagoon

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Summary: Recently a collection of ancient maps was found in the Institute of Marine Sciences of CNR in Venice. The collection includes maps, perspective views, pilot books and ancient manuscripts: this work took into account a selection of maps and documents representing the Venice Lagoon and the Adriatic coast.

The first part of this research focused on the application of a scientific method for digital acquisition of historical cartography; thanks to the Geomatic tools and especially to digital photogrammetry it is possible to acquire metric, semantic and symbolic information and also the three-dimensional shape of the geometrical support to correct the deformations occurred over time.

In order to allow historical and morphological analysis of the Venice Lagoon, one of the main goals of this research will be the creation of a digital catalogue on a web-gis platform with all the ancient maps acquired. In this way it will be possible to query and to overlap the maps in an interactive way, allowing studies and comparisons with the more recent cartography.

The applied procedure of recovery and valorisation of historical cartography is divided into three different phases: acquisition, georeferencing and data elaboration of maps in a digital environment. This research underlines the application of a scientific procedure for the conservation and valorisation of the historical Cartographic Heritage.

Introduction

The Institute of Marine Sciences of CNR in Venice has an important collection of ancient documents preserved in its historical library. This remarkable archive of ancient maps, pilot books, documents, books, and unpublished manuscripts has been recently rediscovered during the renovation and restoration works of a complex of buildings near the Biennale Gardens; these works included the Villino Canonica (Fig. 1) that is the former headquarters of the Institute of Adriatic Studies (ISA) and the Italian Thalassography Committee in Venice, now part of the Institute of Marine Sciences of CNR.

The ISA was founded in 1932-33 by Giovanni Magrini within the Italian Thalassography Committee (Bona 2005; Linguerra 2004), with the aim of studying in depth the Adriatic and the Balkan side of this sea, claimed by the fascist Italy, in order to culturally legitimize the reconstitution of the ancient Gulf of Venice.

For this purpose the archive was accumulated with a relative thematic coherence largely through resources. Even if the members of the Institute produced a relatively rich series of essays and articles on the history of Venice and its influence on the Adriatic area, most of the manuscripts and maps remained unpublished after the end of the Institute and progressively forgotten after the Second World War. In fact, in this period the Thalassography Committee (then called Marine Biology Institute) based its activity exclusively on marine biology and fisheries sciences.

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Figure 1. The Villino Canonica and its location.

The rediscovery of this untouched archive dated back to the late 2010, when a member of the Institute was charged to select and save the ISMAR librarian Heritage before the renovation of the buildings. The ISA archive includes 109 heterogeneous maps, manuscripts, water-colored sketches and engravings, regarding lots of different topics: for example, some important represented themes are Venice and the Lagoon from the Po Delta to the Tagliamento river, the so-called Gulf of Venice (the ancient name of the Adriatic Sea), with a particular reference to the Balkan coast formerly dominated by the Serenissima Republic. Moreover the whole Mediterranean and World maps from 16th to 19th century, a Dutch pilot book of 1654, a Venetian pilot book of 1792 and an original copy of the *Atlante Veneto* by Vincenzo Coronelli were also found. This Heritage includes documents describing four centuries of history of the Adriatic and the whole Mediterranean area, offering a unique documentation of representations and modifications of coastal morphology during the centuries.

Now the most precious maps and pilot books have been temporarily assigned to the Cartography and GIS Lab (CIRCE) of the IUAV University of Venice. Recently the ISMAR (partly funded by RITMARE Project) has started a collaboration with the IUAV University of Venice (Ceregato *et al.* 2014) with the aim of planning how to valorise their historical map collection through the digitization, the georeferencing and the cataloguing of a selection of maps and pilot books not well known or not published yet: one of the first result was “The map is not the territory”, an exhibition on the evolution of cartography opened to the public in 2013.

This work has to be followed by a portal web-gis via Geonode (currently under construction) with the aim of publishing in a digital format the vast majority of ISMAR historical maps.

This procedure enables the interactive viewing of historical maps: their overlap is useful for the comparison with more recent maps, orthophotos and satellite images. The ISMAR-IUAV multidisciplinary study has the final aim of offering to scholars and researchers the public access to interactive maps, atlases and the connection with external library resources.

This work focused on the study of transformations of the Lagoon environment and especially on the city of Venice and the Adriatic coast up to Greece. The research has the aim of identifying and testing the digitization, georeferencing and data processing’s techniques that better fit for the conservation, valorisation and divulgation of the analysed Heritage.

The work was divided into two main parts: in the first phase some tests on the maps’ digitization were made, whereas in the second phase the acquired maps were georeferenced in respect to an actual cartography. Finally, the deformations of the different maps were shown and studied applying a procedure known as strain analysis, already tested in past researches by the Photogrammetry Laboratory of the IUAV University of Venice.

The digitization phase

The first phase of this work was the digital acquisition of the historical cartographic Heritage of the ISMAR CNR Institute. In the field of Geomatic and Cartography the problem of digitization of the historical Heritage is an open and very important question. The ancient cartographic documents are an immeasurable historical and cultural Heritage that usually presents a lot of decay's problems.

In the digitization phase it is not always possible to use contact scanner, as the roll or flatbed scanners, because the physical support has usually deformations that need to be evaluated in order to survey the geometric content of a map.

During the last years different methods were proposed for the digitization in order to record in the digital format both the three-dimensional surface of the support and the bidimensional image with a high resolution (Adami *et al.* 2007; Daniil *et al.* 2003; Tsioukas *et al.* 2009; Tsioukas *et al.* 2012; Balletti *et al.* 2014).

Photogrammetry is the most used technique in this particular field (Ballarin *et al.* 2014a; Ballarin *et al.* 2014b): through the acquisition of photograms with a correct capture's geometry it is possible to create a three-dimensional photogrammetric model; in this way it is possible to digitize not only the radiometric values, but also the metric content and the deformations of the physical support.

It is really important to choose the more suitable digitization's method for the historical map that we have to acquire. In this case study, the most recent maps had few deformations of the support and they were in a good state of conservation: for this reason we decided to acquire the bigger maps with a HP Design Jet 4200 (A0 format) scanner with a 300 dpi resolution. On the other hand the smaller maps were acquired with an Epson GT 20000 (A3 format) scanner with a 600 dpi resolution. In this way it was possible to acquire in a digital format the historical maps with a high resolution.

However the most part of maps were not in a state of conservation suitable for a scanner acquisition; for this reason they were digitally reproduced with an acquisition based on photographs. In this case a digital camera Nikon D800 was used: it has a CMOS full frame sensor (35.9x24 mm) and the images were acquired with the highest resolution (7360x4912) and with a fixed lens (60mm).

The digital acquisition was realized with only one photograph for the most of the analysed maps because of their reduced size and the small deformation of the support. The 2D photogrammetry method was often used for the historical maps' digitization and many researches were done applying this methodology to ancient maps; however for the more complex cases the three-dimensional digitization is the only procedure to use.

The extended size and the very bad state of conservation of a map are usually fundamental for the application of the 3D photogrammetry in the digital acquisition of historical maps. The bad condition of the original support is the first index we should take into account in this phase: the deformation is usually caused by temperature and humidity variations occurred during the years. Moreover the radiometric content of a map is usually on a wooden support or made by another material that is not always a flat surface, as for the case of atlas or ancient bound documents. For this reason the photogrammetric method is an interesting answer for the necessity of acquiring not only the radiometric content but also the geometry of maps and their support, without touching them and avoiding additional damages. Considering the state of conservation and the maps' dimensions, all the previous methods described above were applied in the particular case of the

cartographic Heritage of the Institute of Marine Sciences ISMAR CNR in Venice. The 3D photogrammetry was very useful for the very decayed maps, as for example the historical map of Italy drawn by Giovanni Maria Cassini and dated to 1793 (Fig. 2) or for the map of Venice drawn by Bernardo and Gaetano Combatti and dated to 1846.



Figure 2. The acquisition of Cassini's historical map of Italy.

In this last case-study, we acquired seven different photographs in order to cover the whole map and to have their correct overlapping; the digital camera Nikon D800 with a 60mm lens was used. The images were captured with convergent optical axes and a semi-circular geometry with respect to the position of the map.

Then a photogrammetric model was created using the Structure from Motion software Agisoft Photoscan Professional (URL 1). The final model had 100000 faces and it was then scaled on a measured distance. In the end, an ortho-image with a pixel dimension of 0.1mm was created as a final product (Fig. 3).



Figure 3. The Combatti map's photogrammetric model and the final orthophoto.

Notes on the IUAV Online Cataloguing

The Cartography and GIS Lab (CIRCE) uses an online cataloguing system organized by record that follows the standard ISBD - Cartographic Materials (CM); each record corresponds to a card containing the technical data of the map with the possibility to also upload its image. All lines provided by the standard are filled with the listed title, author, date, scale, projection, the enrolment and geographical identification references (if they are known).

Furthermore, there are also other information as historic place names, recurrent signs, the bibliographical notes and annotations that can help the researchers to reconstruct sources and information about the semantic content of a map.

The topographic log found at the ISMAR library is the fundamental document used for the cataloguing; the library's documents were also useful for the most maps and pilot books' bibliographic reconstruction.

The georeferencing phase

The second phase of this research focused on the georeferencing methods for the ISMAR cartographic Heritage, once it was acquired in a digital format; as already stated, map's analysis focused mainly on the city of Venice and the lagoon. The Roma40 system, oriented in Rome Monte Mario, was chosen as geodetic datum, whereas the Gauss-Boaga (west zone) was selected as the cartographic reference datum. The Veneto orthophoto (2007) was employed as reference map to georeference the historical maps of Venice Lagoon.

The geometric transformations applied to a cartographic image can be classified into two main categories: global and local transformations; obviously, the choice of which transformation we have to use depends on the map that has to be georeferenced (Balletti 2001; Balletti *et al.* 2001).

Global transformations are those whose parameters are valid for any point of the image after the model is chosen. The position of each point will be calculated applying the parameters starting from the control points. These are the traditional plane transformations that relate a system of points to another set of points in a one to one correspondence, realizing the transition from the o, x, y system to the O, X, Y system. On the other hand, the local transformations are calculated for each individual point of the image and have local validity. The aim of using local transformations is to deform only a part of the image without applying substantial modifications to the whole map. The global transformations are used in the referencing procedure such as general transformation. At the same time, it is possible to evaluate deformations through the analysis of the residuals. Usually a higher than necessary number of points is used and the value of parameters is calculated with a least squares adjustment; in this way it is possible to evaluate the results of transformation through the analysis of residuals' distribution and verify the transformation's accuracy with respect to the two sets of points used.

The georeferencing procedure is fundamental to obtain an historical series of maps in the same reference system that in this particular case is the official Italian Cartography; the data that can be extracted from maps can be compared to a more recent cartography and some useful analysis can be done.

The georeferencing work of ISMAR cartographic Heritage was done using the ESRI ArcGis software (URL 2). This application, and in particular the ArcMap module, allows to apply various transformations, after the recognition of the tie points on both the two maps. We have the choice of using a polynomial, a spline, adjust, or a projective transformation to determine the correct map location for each cell in the raster. In particular, the applied transformations in this research were the affine, the spline and the adjust transformation, chosen from time to time according to the characteristics of the map itself.

The first-order polynomial transformation (or affine transformation) is commonly used to georeference an image: this kind of transformation is used to shift, scale, and rotate a raster dataset; it used a polynomial function built on control points and a least-squares fitting algorithm. It is optimized for global accuracy but does not guarantee local accuracy. The spline

transformation is a rubber sheeting method useful for local but not for global accuracy. It is based on a spline function and it requires a minimum of 10 control points: it transforms the source control points exactly to target control points. This transformation is useful when the control points are important and it is required that they have to be registered precisely. The adjust transformation optimizes both global and local accuracy; it requires a minimum of three control points and it adjusts the control points locally to better match the target control points using a TIN interpolation technique.

The first historical cartographic items georeferenced were the Lagoon Atlases and the Denaix map. Once the maps were digitized by a flat scanner, the first question arose whether the georeferencing has to be done on the whole map mosaic or on each single sheet. We did some tests georeferencing separate sheets, but the results were not satisfying: the main difficulty was finding the homologous control points on historical maps; in fact, usually, sandbanks or boundaries are represented with a different morphology in respect to the actual cartography. Therefore, we decided to proceed first of all doing the mosaic of all the sheets and then applying a georeferencing transformation to the whole obtained image in the current cartographic reference system.

We did some test on which transformation has to be applied and we analysed the obtained residuals; then we decided to apply the spline transformation for the Atlas II, III and the Denaix map, whereas the adjust transformation was applied to Atlas V (Fig. 4).

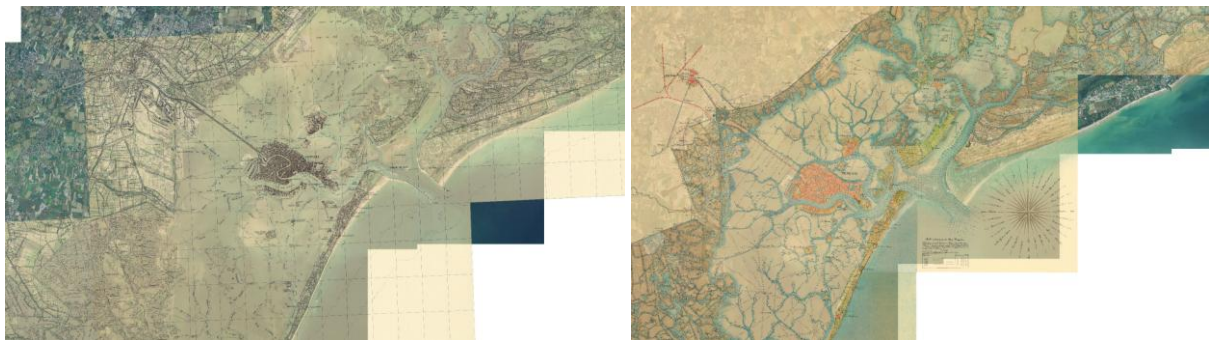


Figure 4. The georeferenced Atlas V and III.

One of the main purposes of the research was the re-projection of the georeferenced maps on a web portal, creating an overlapping of different layers useful for the analysis of all the morphological changes occurred over time. For this reason, it was decided to apply transformations able to have effects both globally and locally, in order to obtain a good semantic and geometric coherence of historical data compared with the current one.

A different procedure was adopted to the historical map of Venice surveyed and drawn by Bernardo and Gaetano Combatti (1846) at the 1:3000 scale; a first degree global transformation (affine) was applied to the map in order to contain its deformation. As mentioned before, we used the photogrammetry method for digitizing this map because of the deformations of its original support.

Then the whole sheets' mosaic was georeferenced keeping the slight gap between the different original sheets (Fig. 5). The result is a total RMS error of about 13 meters; in this case, the total error would probably be lower processing every single sheet, but control points were missing in most of them.

Moreover, some other image analyses were made on this particular map: the nineteenth-century map was compared with the photo-plan of Venice, always re-projected in the Gauss-Boaga West

zone projection system. For this comparison we decided to apply the method of the strain analysis.



Figure 5. The Combatti's map georeferenced in respect to the Veneto ortophoto.

Data processing: the strain analysis for maps' comparison

The strain analysis describes the behaviour of a map compared with another one: the elasticity theory can provide fundamental information about the geometric differences between two representations of the same object (Boutura & Livieratos 1986; Balletti *et al.* 2014; Dermanis & Livieratos 1981a; Dermanis & Livieratos 1981b). Introducing invariant quantities and applying an analytic process, it is possible to obtain an objective and quantitative description of a map's geometrical distortion compared to the other one.

First of all the points' distribution has to be as homogeneous as possible; in fact, their concentration in a specific area causes a negative result of the map evaluation. The method uses as an input the differences of the coordinates of common geometric elements in the maps after having eliminated the translation, rotation and scale differences between the two sets of points, which means after having performed the best fitting on the two sets using a roto-translation with a scale variation. The coordinates' differences are considered as if they were the differences of coordinates of points on a "body" in two different stages: an unstrained status corresponding in our case to the reference map and one under strain that corresponds to the historical map.

To perform the strain analysis, the Photogrammetry Laboratory of the IUAV University of Venice implemented the *Strain_Map* software, which allows the calculation of the elastic parameters: starting from the control points, the area is divided in triangular patches, using the Delaunay triangulations as a specific algorithm. The triangulation identified on the historical map is transferred on the current map using homologous points. This means to properly connect the points of a set in order to create a set of triangles, minimizing the sides' lengths.

Once we have computed the triangulation from the control points we have to assign to the barycenter of each triangle the parameters calculated: for all the other points, the values are obtained through an interpolation based on the Kriging algorithm. After this procedure we can draw the isolines of the strain values: among the most important parameters calculated there are the expansion Δ , the maximum stress γ , the rotation ω and the dissipated energy W ; these parameters show the geometrical variations of the two different maps. In particular the parameter W shows both the isotropic and anisotropic deformations, which means the energy dissipated in order to perform the map B in the geometric coincidence with the original map A.

The importance of the strain analysis procedure is that it offers strong criteria to evaluate if maps need relevant corrections. For example, if we have to correct areal and distance quantities the

parameters that we have to consider are the expansion and the maximum stress (positive values for the expansions means positive areal corrections).

Within this research, the method of strain analysis was applied to the 1846 Venice map using as coordinates reference system the photo-plan of Venice re-projected in the west zone.

As we can see in the figures below processed by Surfer software (URL 3), the two analysed maps do not have macro differences, except in some well-defined areas. These critical points, where surely there isn't a one to one correspondence between the two maps, are situated in the outlying parts of the city, such as San Michele island in the North Lagoon, the Giardini and S. Elena's area, the zone of Salute and Punta della Dogana and, finally, a part of Giudecca island. Particularly, San Michele island, that is now the monumental cemetery, presents a north-east translation in the historical map. This "voluntary" error (done in order to represent the island within the frame of the map) is easy to see in Figure 6.

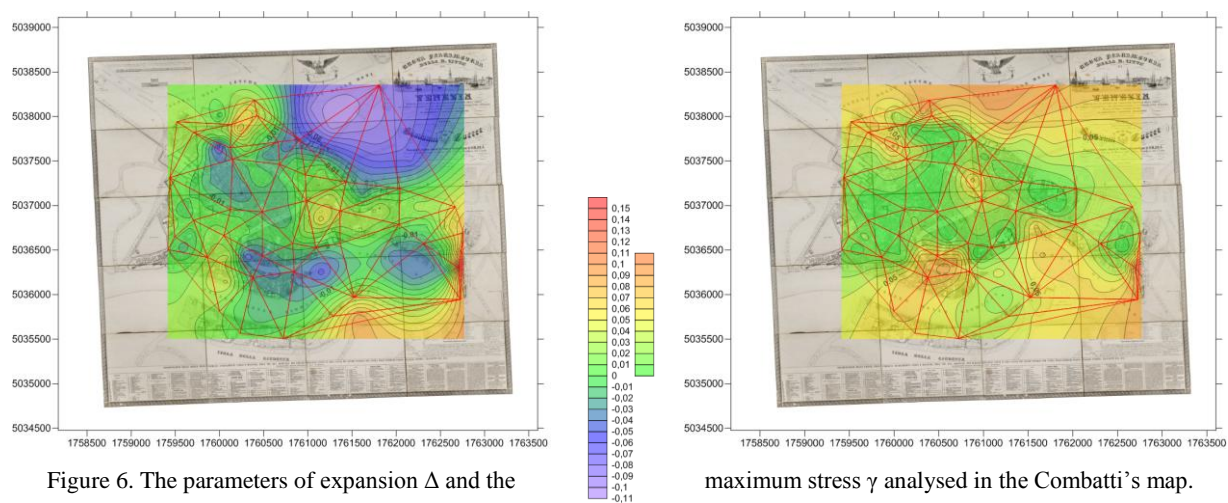


Figure 6. The parameters of expansion Δ and the

maximum stress γ analysed in the Combatti's map.

The GEONODE portal

Within the collaboration between the IUAV University of Venice and the CNR Institute, ISMAR realized a web-gis portal to collect the digital historical maps. The web portal was implemented with the open source software GEONODE (URL 4) that will provide the interactive maps' consultation and their overlapping will allow an easy visualisation of differences between historical maps and most recent layers (recent cartography and remote-sensing images).

ISMAR has a great experience on environmental data sharing and, in particular, is partner of the Venice Lagoon Atlas project (URL 5) with the main goal to make information about Venice Lagoon available to a wide public and experts. This project is obviously connected to the whole work and will help us to share the new digitized maps.

The tools provided by the web-gis portal will allow users to overlap different layers from different external sources through WMS, WFS and WCS services and to save the new maps inside the portal.

The comparison of maps from different historical periods and drawn by different designers will allow all the researchers to study the coastline evolution, the lagoon morphology and rivers path occurred over time (Fig. 7).

The use of WGS84 international reference system (directly re-projected for the online publishing) and the choice of sharing maps through OGC web-services (URL 6) will permit to share maps and

to also use this system in different ways, both online in the web portal and in a GIS-desktop software. The utilisation license that we are going to apply is not yet decided but it will be as open as possible.



Figure 7. On the left the Lessan's map overlapped on the 2012 ortophoto; on the right a detail of the Denaix's map.

Conclusions

The importance of this research is the awareness of the historical maps' decisive role in the territory study and especially for its future planning. In fact, the place's image represented in a map is not neutral: it is the result of interpretations and choices made by the mapmaker; it is the product of conventions and stylistic choices depending on the specific historical period in which the map is contextualized. The lack of codification generates a variety of languages, but the individual importance of documents still remains fundamental for the study and interpretation of the current territorial morphology.

In a society in which the media are usually visual, the cartographic document represents a message that is extremely incisive and easy to understand; for this reason it can be considered a very important educational tool, a concrete basis for the analysis of a place considering physical, historical, economic and social components. This consideration highlights the importance of georeferencing and online publishing maps for the analysis of the territory.

This research focused on the new accessibility concept of a shared knowing heritage, which also is based on the hopeful and increasing integration between different professional and scientific disciplines; the dynamic and forward-looking collaboration with researchers and organizations will be fundamental in order to obtain new products and results, which become a powerful cognitive and educational tool only thanks to this interaction.

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URL 2: <http://www.esri.com/software/arcgis/arcgis-for-desktop>

URL 3: <http://www.goldensoftware.com/products/surfer>

URL 4: <http://geonode.org/>

URL 5: <http://atlantedellalaguna.it>

URL 6: <http://www.opengeospatial.org/standards/wms>