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Walking through historical maps of Venice

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Summary: The mapping and GIS Laboratory of the University IUAV of Venice owns several digital copies of historical maps, some of which concern the city of Venice, from the view by De Barbari to the most recent orthophotos. Even the most careful analysis of an historical map rarely -and almost never easily- allows the automatic individuation of correspondences between points/places and modern reality. In this respect, the main difficulty is the impossible application of transformation formulas, in order to link, in a one-to-one way, a point of the historical map and a point detected inside a known reference system.

The purpose of this work is to suggest an adequately reliable methodology in order to allow an immediate and good evaluation of positions on the historical map that correspond to localizations on modern ones, and vice versa. The modern map represents the common ground to evaluate the correspondences among paired points on the ancient maps. This correspondence is calculated in real time and the points are used for the individuation of paths on different maps. The methodology is based on the digitization of some points easily detectable on the first map (reference) and on the historical one. Using these points, a Delaunay triangulation is calculated. Through the correspondent triangles it is possible to obtain, with a good accuracy, the position of every point on the two maps. The results of this study can be visualised for the development of a web application both for mobile systems (smartphones / tablets) –exploiting the availability of their localization sensors (GPS)- and for PC, through the interface offered by browsers. Both of these approaches use the access to map services specifically created for every historical map.

Introduction

The project “historic cartography on mobile devices” develops from the possibility offered by mobile devices (smartphone, iphone, tablet) of geo-localising through embedded GPS receivers the position of the device itself and therefore to provide information about the detected position. A number of software applications use these functions to offer geo-localisation functionalities, using cartographic bases that visualise the territory representing the topographical, geomorphological and infrastructural aspects of the current space.

Our laboratory owns a remarkable cartographic heritage, already largely digitised, and has for some time conducted assiduous work in order to encourage its use and diffusion via the web. The historical maps hold an important place among these materials and we thought it was important to study and propose new modalities to facilitate and valorise their use.

The general aim of this work was the study of a new method, to determine in real time, on a historical map, positions of points that correspond to geographical localisation obtained by GPS systems.

The proposed solution tries to respond to different operational and functional needs that structured our research:

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- Precision of the individuation of points during the setting of the data;
- Respect to the semantic content of the historical map during the visualisation phase;
- Computational efficiency (in real time);
- Applicability of the methodologies to a wide number of historical maps.

In the first phase of this project we chose to use some historical maps of the city of Venice, in particular the view of Venice by de Barbari¹ (1500) some maps of the area of the Arsenale, which is particularly interesting from a point o view of city transformations at the end of the XIX century and the photoplans of 1911 and 1982. The application is completely independent of the maps used, and it allows the visualisation of other maps of Venice, as well as those of other cities, as long as the source is adequate.



Figure 1: Jacopo De Barbari, Bird's eye view of Venice (1500).



Figure 2: Some of the Martini's plans of the area of Arsenale.

¹ This bird's eye view of Venice is one of the most spectacular achievements of Renaissance printmaking. It was printed from six large woodblocks on six sheets of paper which were then joined together to cover an area of nearly four square metres. The print was based on careful surveys of the streets and buildings of Venice, almost every one of which can be seen clearly. One topical element of the scene is the temporary flat roof on the great bell tower in St Mark's Square which was erected after a fire in 1489. The blocks were later altered to show restoration work done in 1511-14.

Methodological notes

Relationship between historical map and maps of today

From a methodological point of view, the first decision concerns the choice of how to confront the problem of the relationship between the different maps.

Determining the correspondence between the same points represented in different reference systems, of which the geometrical parameters are known, is a relatively simple problem. The subject is much more complex when we have to deal with cartographic representations that have been drawn without a specific geometric-projective reference. For these maps, working with the classical methods of cartographic projection is very difficult, when not impossible. Dealing with this problem means first of all identifying a methodology that allows the determination of a one-to-one correspondence between the points detected by the geo-localisation provided by the GPS (geodetic reference system: WGS84, geographic coordinates), and the correspondent points in the historical maps. Broadly, it is possible to use two different approaches to solve this problem. The first studies the possibility of georeferencing and sampling, in a geometrically correct way, a deformed image, applying global and local transformations and finally assigning the geometry of one image (the historical map) to the other (reference map). However, this procedure determines, especially for particularly deformed maps, not just the loss of the geometrical content of the original map, but also and more seriously its semantic content which is particularly important in historical maps.

Historical cartography is surely a sector in which these questions concerning referencing and transformation have great importance.

Even if generalising is always difficult, and perhaps unfair, historical cartography has some common characteristics, such as:

- An undefined reference system
- An approximated projective system
- Uncertain metrical content
- Semantic content that is difficult to interpret.

These characters are usually not homogeneous, if we consider maps from different times and different authors. This leads to the necessity of dealing with each transformation problem singularly for every single map, with consequent limitations due to the computational complexity and the overall quality of the transformation process.

Given that historical cartography is a documentary source of great importance for the qualitative and quantitative (metric) reading of the territory represented, the considerations mentioned above suggest great caution in the use of geometric transformation of those maps, because often it is not acceptable.

The second approach, the one that we adopted, can be defined “research of the punctual correspondences” and it entails the maintenance of the original geometric characteristics of the historical map: no deformations are introduced, so that its semantic content is unaltered, and we avoid the necessity of pre-elaborating the original image. The problem of the correspondence between homologous points of the historical maps and the reference is then solved immediately and visualised in real time.

In the following paragraphs we will illustrate in detail the adopted solution.

Preparation of the data

The methodology applied to this project requires a preparatory phase for the data that takes place from the digital reproduction of the mapping, acquired by scanning. Subsequently, analysing the images on the screen, one can identify a considerable number of points of the buildings of Venice, for which we can find a correspondence between the basic image (UTM projection, zone 33 North, geodetic reference system WGS84) and the historical map. These points have to be uniformly distributed on the whole map, and part of them has to be located along the perimeter of the area of interest. This method will allow an adequate coverage of the whole map by tessellation (defined in this case by the Delaunay triangulation), which constitutes the main structure for the individuation of homologous points between the two maps. The number of identified points will be much larger, the bigger the “deformations” of the historical map are: in this way, the algorithm will identify the correct localisation with a better accuracy.

The historical map used for this case study is the view by de Barbari (1500), digitised in such a way that did not introduce any deformation on the original support. It is registered on a *jpg* raster file: this format allows a good compromise between the file dimension and the respect of the original image quality. Image pixels lie on a Cartesian reference plan (x, y). The georeferenced basic image is a recent orthophoto of the city of Venice. The following figure illustrates the preparatory phase, when the homologous points are detected according to the specific reference systems of the two images.

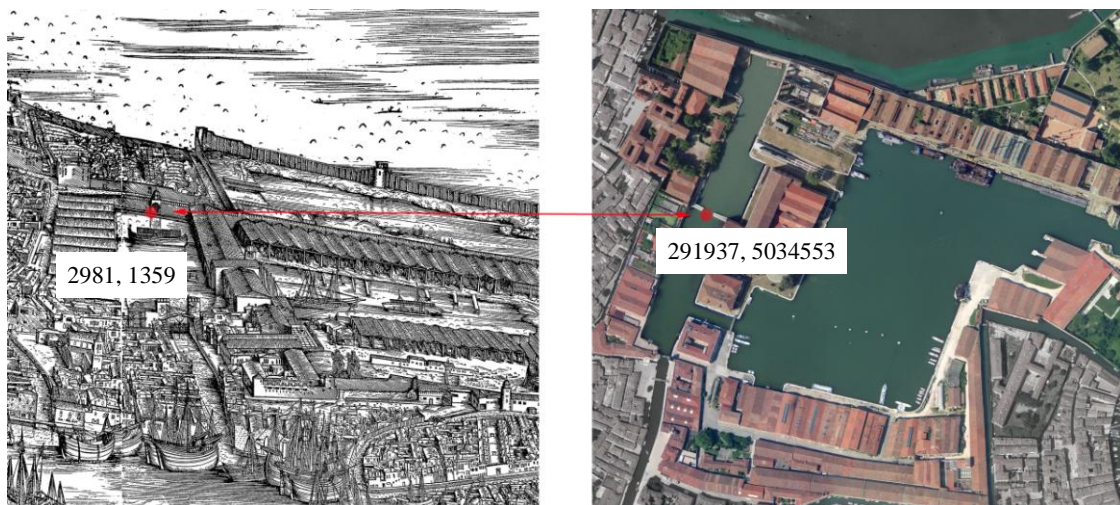


Figure 3: Correspondence between the coordinates (pixel, column-row) of the image of the historical map and the UTM coordinates (meters) of the reference image.

For each point identified on the reference map, its UTM coordinates and the pixel values (row, column) of $i_{2981, 1359}$ on the historical image are registered.

Starting from the set of points previously identified, the Delaunay triangulation is built and registered in shapefile format. Here, we want to briefly recall some characteristics of this geometric construction, in order to demonstrate why we chose it as a reference structure to which we applied the computation algorithm for the determination of homologous points.

Given a set P of point in a plane, a triangulation T of P is a Delaunay triangulation $DT(P)$ if the circumcircle of any triangle of T does not contain a point of P . Furthermore the DT maximizes the minimum angle of all the angles of the triangles in triangulation; consequently it tends to avoid narrow triangles as they have large circumcircles compared to their area. It is possible to general-

ize the Delaunay triangulation to more dimensions, so it can be applied not just to a planar surface. Thanks to these properties, the DT provides a good solution to the terrain model problem, and we can consider it an efficient geometric structure to achieve our target.

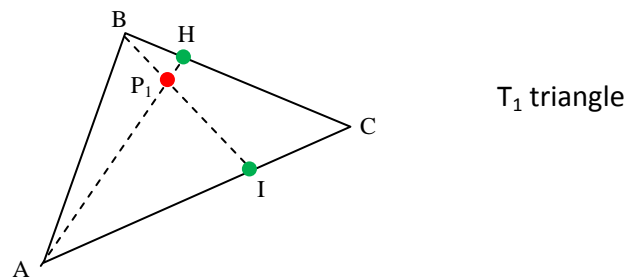
Correspondences, coordinates-pixels

This phase coincides with the estimation of which pixel in the de Barbari view corresponds to the UTM point identified by the GPS. The solving algorithm is based on the use of corresponding triangles identified on the base structure.

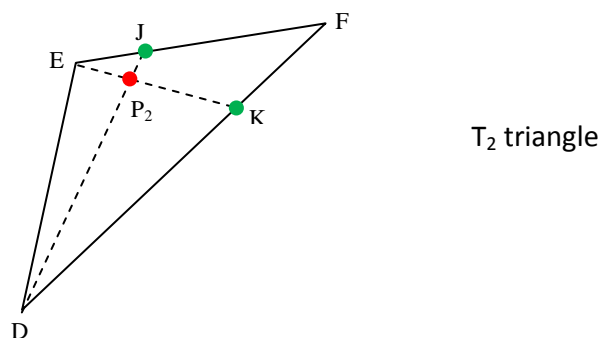
Starting from correspondent triangles, we can use different solutions. Below, two possible alternatives are illustrated.

Vertex-point method

T₁ is the triangle with UTM vertexes; T₂ is one with image coordinates vertexes (pixels). The vertexes corresponding to the two triangles are A-D, B-E and C-F.



On T₁, intersecting the side BC with the straight line passing through A and P₁, we can identify the point H. This divides BC into two segments: BH and HC. On T₁ again, the side CA intersects the straight line that passes through B and P₁. This identifies the point I, which divides AC into two segments: CI and IA.



On T₂, we calculate the lengths of those segments, which correspond to BH (or HC) and CI (or IA) and we superimpose them on the correspondent sides EF and FD, so that we will identify the points J and K. Therefore:

The length of the segment EJ will be given by the proportion

$$BH / BC = EJ / EF$$

from which we will obtain

$$EJ = BH * EF / BC$$

the length of the segment FK will be given by the proportion

$$CI / CA = FK / FD$$

from which we will obtain

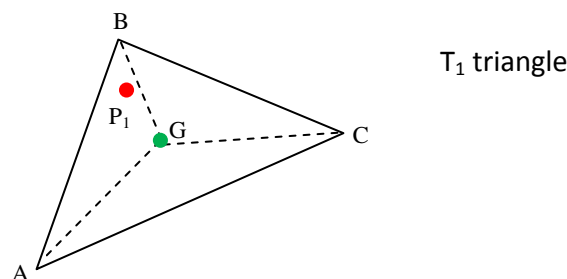
$$FK = CI * FD / CA$$

At this point, linking the vertex D to the point J and the vertex E to the point K, we will detect two segments that intersect each other in the point P₂, which is the point we were looking for. Given that the pixel coordinates can assume only integer values and that the pixel coordinates of P₂ will generally be represented by decimal values, we will have to round them up in order to obtain the integer of the pixel coordinates.

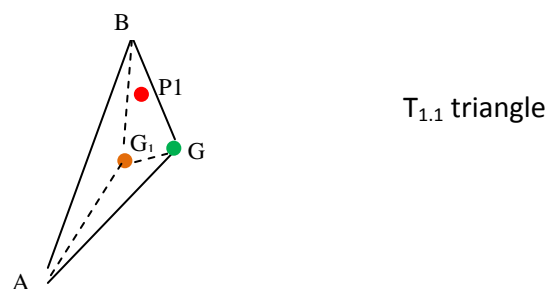
Another method, similar to the one just described, entails using as reference segments those intercepted by the perpendicular to the sides passing through that point. This method – which we could call perpendicular-point – leads to very similar results to those obtained through the vertexes-point method.

Barycentre method

In this case, though maintaining triangles as base elements of the procedure, the approach is different because the research of the corresponding point entails a cycle loop that carries on until the desired precision is reached. Again, T₁ represents the triangle with UTM vertexes.



The cycle loop starts from the T₁ triangle, which contains the point P₁. Starting from the UTM coordinates of the triangle vertexes, the coordinates of the barycentre G are calculated. On the triangle AGB, inside which the point P₁ falls, we can apply the same procedure to detect the barycentre that we used for the triangle ABC: we calculate the coordinates of the new barycentre G₁. In the figure below, P₁ is inside the triangle BG₁G: repeating the procedure we can identify a new triangle, smaller than the previous one, and containing P₁.



The loop can go on until the distance between the new barycentre and P_1 is smaller than a predefined value. Once this value is reached, we can assume that the barycentre found represents with sufficient accuracy the position of P_1 . Otherwise, we can verify if the application of the *vertex-point* method gives a smaller error at the end of the loop. With the same procedure adopted for the triangle T_1 , we act on T_2 and on all the other triangles identified by the barycentre method. The number of loops used on the triangle T_2 will be equal to the one executed on the triangle T_1 .

The points at a predefined minimum distance from the sides of the triangles are considered lying on the sides themselves. Therefore, the research for the correspondent pixel becomes just a simple ratio between the identified segments.

The application

The applications development needs to take into account some elements, which limit – or just influence – interactions between mobile devices and users. Probably, the most obvious one is the quality of the display (resolution and dpi). Normally dynamic layouts help to overcome differences in resolution, but the density of pixels on a device's screen can cause some problems in the correct visualisation of raster objects. In fact, bitmaps cannot always be correctly scaled. In these cases, it is possible to load bitmaps at different resolutions, depending on the device resolution or, like in our solution, provide a tiled map service, which serves ready images for each defined scale level.

Even the presence of sensors inside the mobile device can vary according to the different models. The quality of the sensors themselves can be very different and therefore they can affect the efficiency of the application. For example, the accuracy of the GPS inside those devices has a margin of error that varies from a few to ten meters. Also, the signal quality can influence considerably the mean error on the localization.

These considerations, linked to the technical aspects of mobile devices, are enough to define the limits inside which we can accept the accuracy on the localization of points (pixels) on the historical maps corresponding to the different localizations detected by the GPS system. In practice, we can say that this limit cannot be smaller than the order of magnitude of the mean error caused by the survey method. Obviously, as the error does not vary according to the scale of visualisation, the representation of the historical map on a large scale does not provide bigger precision in the GPS positioning. To the errors caused by the hardware accuracy we have to add those introduced in the data preparation phase, that are due to the nominal scale of the map and to the precision of the operator in the detection of correspondent points. The order of magnitude of these errors is inversely proportional to the scale of the map. Therefore, for maps on a scale between 1:20000 and 1:50000 we can consider it included in the minimum error given by the geolocation system. With a good approximation, the average total error can be computed as the sum of the two errors mentioned.

At this phase, the development of the application has reached the following functionalities:

- real time tracking of the user's path
- choice of the map to be displayed
- select a location from a list of predefined points of interest
- switch from one image to another zooming on the same location
- zoom, pan and reset to minimum scale
- on board GPS on/off
- application status and ancient map information

At start up, the application checks the on board presence of the GPS sensor. If not, the application starts in GPS off mode: maps are still available but user can only display them, use pan and zoom and select a predefined place from the Places list. Otherwise the application is executed in the GPS on mode and the path tracking starts immediately. Current mobile device geolocation becomes the centre of the displayed map and a symbol is used to show this position on the map. When the user walks around and their distance from the previous marked location is more than a predefined length (currently ten meters), then the application updates the displayed map at the new centre point. If the displayed map changes, the scale does not change and the new map is centred at the new captured GPS coordinates. The user can switch off the GPS sensor: in this case the application executes in GPS off mode. It is possible to view some information about current application status and some map detail. The Reset button provides a fast method to display the current map at the minimum scale.

The figure below illustrates the functional scheme of the application.

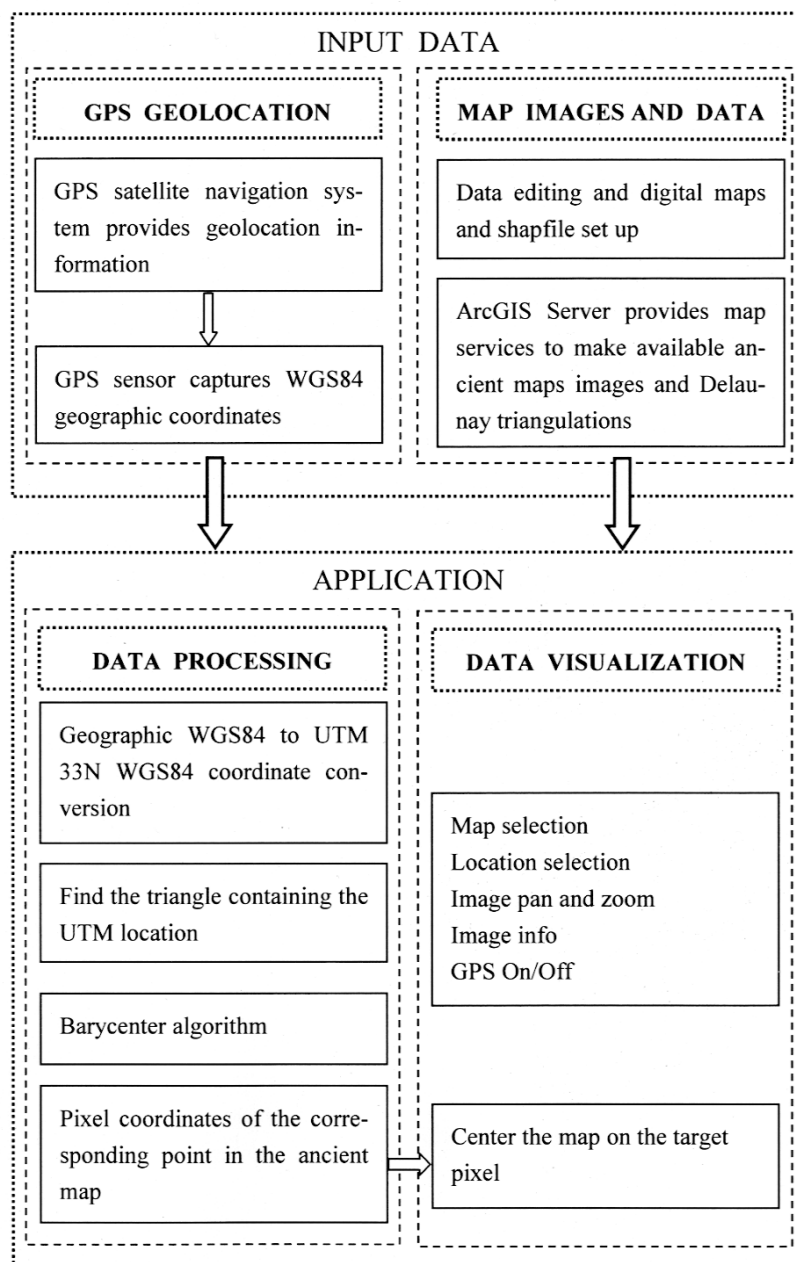


Figure 3: Application scheme: from GPS geolocation to ancient map target pixel.

Conclusion

This work is part of a series of initiatives that are included in a more general project. This project has the main purpose of improving the usability of the cartographic heritage available at our laboratory. The development of applications for mobile devices represents an important step towards the achievement of this goal. In particular, we studied the possibility of visualising in real time and in a georeferenced context the images of historical maps that, for their specific geometric and semantic contents, are not easily understood. The attention in the data setting and the use of specific algorithms for the determination of corresponding points between cartographic coordinates and image coordinates allowed us to obtain good results both in the geographic localisation and in the readability of cartographic documents.

The natural development of this work will be the presentation side by side of historical images: more than one image will be visualised at the same time and geo-synchronised so that the usability and comparison of historical maps will be more versatile for scholars as well as all the possible users.

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